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TECHNICAL ANALYSIS REPORT - AFSWP NO. 507-SAN

RADIOACTIVE FALL-OUT HAZARDS FROM SURFACE BURSTS OF VERY HIGH YIELD NUCLEAR WEAPONS, Sanitized Version

by

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WEAPONS EFFECTS DIVISION

This Armed Forces Special Weapons Project Technical Analysis Report is a staff study prepared for the Chief, AFSWP on a subject of military interest. The conclusions may be modified as new data become available.

MAY 1954

HEADQUARTERS, ARMED FORCES SPECIAL WEAPONS PROJECT
WASHINGTON 13, D. C.

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~~RESTRICTED DATA~~
~~ATOMIC ENERGY ACT [illegible]~~

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ABSTRACT

This paper presents an interim analysis of the problem of radioactive fall-out from the surface detonation of very high yield nuclear weapons. The problem is discussed in general terms, and the results of a specific analysis of the CASTLE BRAVO event are presented. The contours developed by this analysis have been idealized for the purpose of scaling these contours to other weapon yields and to other wind conditions than actually existed at CASTLE BRAVO, and the manner of performing this scaling is described. Examples of scaled contours for 1, 10, 15, and 60 megaton yields are given. The possible courses of defensive action against large scale fall-out are discussed, including the relative advantages afforded by evacuation of the area and by seeking optimum shelter within the area. A detailed summary precedes the body of the report.

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SECRET RESTRICTED DATA ATOMIC ENERGY ACT 1946

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The residual radiation hazard resulting from the fall-out of radioactive particles generated in the surface detonation of very high yield nuclear weapons has been demonstrated in the current CASTLE test series to involve vast areas extending well beyond those affected by damaging blast and thermal effects. Reconstruction of fall-out patterns from the CASTLE BRAVO event, using the preliminary data available at Hqs., AFSWP, leads to the conclusion that land surface detonation of a 15 megaton yield weapon can be expected to deposit radioactive fall-out over an area of the order of 5,000 square miles or more in such intensities as to be hazardous to human life. Indeed, if no passive defense measures at all are taken, this figure probably represents the minimum area within which nearly one hundred per cent fatalities may be expected.

The location of the bulk of the hazard area with respect to ground zero is dependent primarily upon wind direction and velocity, and may be expected to cover a roughly elliptical pattern extending downwind from the burst point. Figure A is an idealized representation of how the total dose contours from a 15 megaton land-surface burst with a 15 knot effective wind may appear at 50 hours after burst time. It will be seen that the area representing an accumulated lethal dose of 500 roentgens extends about 180 miles downwind and is about 40 miles across at its widest point. These contours are based directly upon survey data taken after the CASTLE BRAVO event.

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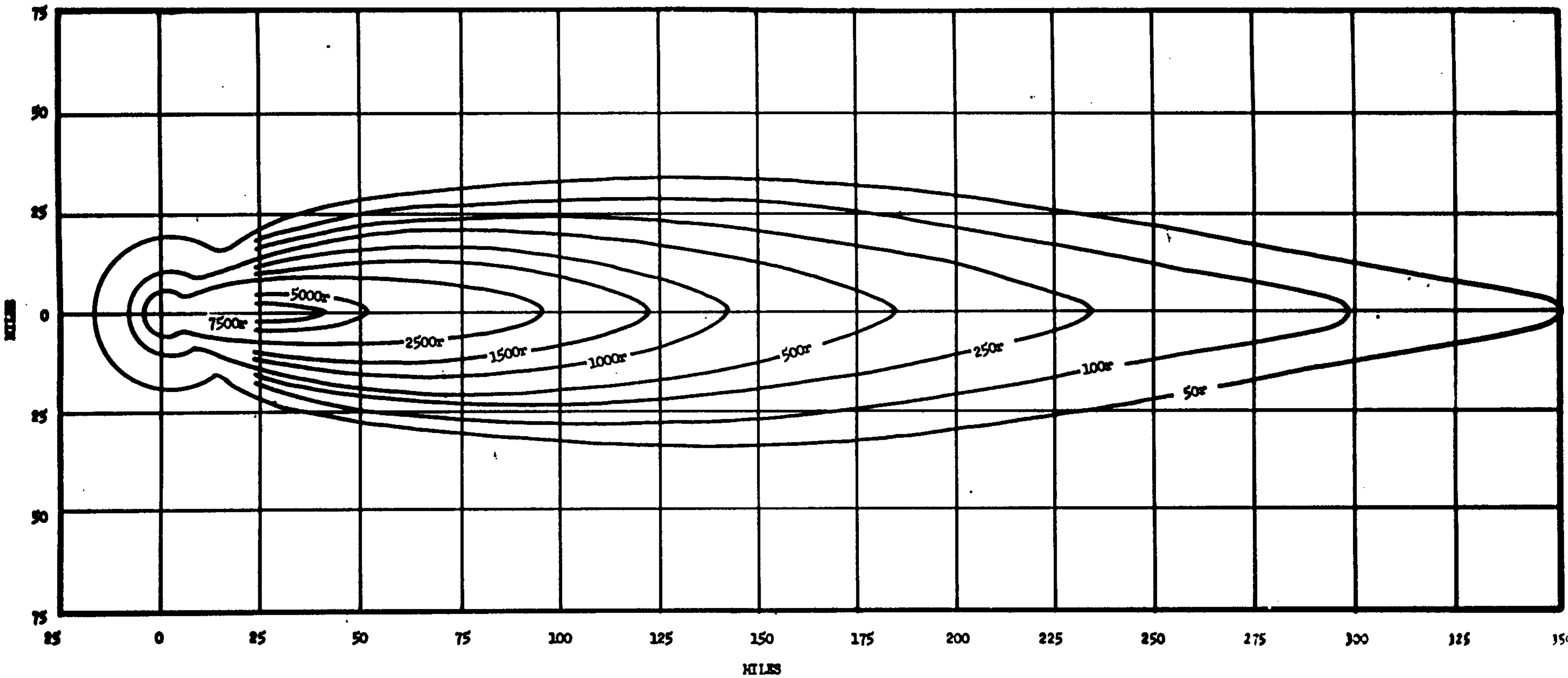
Fig. A TOTAL DOSE FROM TIME OF FALL OUT TO H+50

Idealized Fall-out Contours for a 15 MT Land-surface Burst with a 15 Knot Effective Wind



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The approximate areas involved for dosages accumulated up to 50 hours after shot time are as follows:

2,000 roentgens	1,000 square miles
1,000 roentgens	3,400 square miles
500 roentgens	5,500 square miles
200 roentgens	9,400 square miles
100 roentgens	13,000 square miles

In order to obtain estimates of contaminated areas which are probably involved for other yields in the megaton range, it is postulated that scaling based upon simple conservation of material will probably not introduce serious errors for yields between 1 and 60 megatons, using 15 megaton input data. On this basis, one scales linear dimensions and contour values as the cube root of yield, and areas as the two-thirds power of yield. Scaling in this manner, one obtains the following approximate contour dimensions for a cumulative dose of 500 roentgens in the first two days, assuming a 15 knot effective wind:

Yield	Contour Length (miles)	Contour Width (miles)	Contour Area (square miles)
1 MT	52	12	470
10 MT	150	34	3,900
15 MT	180	40	5,400
60 MT	340	70	18,000

It must be recognized that these vast danger areas apply to personnel in the open, unshielded by buildings or even rough terrain.

The shielding afforded by an ordinary frame house may effectively reduce the size of the hazard areas by a factor of about two, and a basement shelter by a factor of ten or more. Virtually complete protection against the lethal effects of radioactive fall-out can be obtained if personnel have protection equal to or better than that afforded by a simple underground shelter with at least three feet of earth cover, and if they are evacuated after a week or ten days in such a shelter.

One may draw the following conclusions from this analysis:

a. Very large areas, of the order of 5,000 square miles or more, are likely to be contaminated by the detonation of a 15 megaton yield weapon on land surface, in such intensities as to be hazardous to human life.

b. The fact that a large percentage of the radiologically hazardous area will lie outside the range of destructive bomb effects for normal wind conditions, extending up to several hundred miles downwind, makes the radiological fall-out hazard a primary anti-personnel effect.

c. Accurate pre-shot prediction of the location of the hazardous area with respect to the burst point is virtually impossible without extensive wind data at altitudes up to about 100,000 feet, owing to the sensitive wind-dependence of the distribution mechanism.

d. The fall-out contaminant can be expected to decay at such a rate that all but the most highly contaminated areas could be occupied by previously unexposed personnel on a calculated risk basis within a few days after the contaminating event; and even these highly contaminated areas may then be entered briefly by decontamination teams.

e. Passive defense measures, intelligently applied, can drastically reduce the lethally hazardous areas. A course of action involving the seeking of optimum shelter, followed by evacuation of the contaminated area after a week or ten days, appears to offer the best chance of survival. At the distant downwind areas, as much as 5 to 10 hours after detonation time may be available to take shelter before fall-out commences.

f. Universal use of a simply constructed deep underground shelter, a subway tunnel, or the sub-basement of a large building could eliminate the lethal hazard due to external radiation from fall-out completely, if followed by evacuation from the area when ambient radiation intensities have decayed to levels which will permit this to be done safely.

g. It is of vital importance for individuals in hazardous areas to seek optimum shelter at once, since the dosage received in the first few hours after fall-out has commenced will exceed that received over the rest of a week spent in the contaminated area.

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RADIOACTIVE FALL-OUT HAZARDS FROM SURFACE BURSTS OF VERY HIGH YIELD NUCLEAR WEAPONS

I. INTRODUCTION

Of the eight nuclear weapons or devices which have been detonated on the surface by the U.S. up to this time, only two have been instrumented in sufficient detail to permit the construction of radiation dose rate contours with reasonable accuracy. The fall-out patterns from the low-yield JANGLE-S event in Nevada (1.2 KT) in November 1951 were completely documented, and established that a surface burst of a nuclear weapon or device is potentially a highly contaminating event. In November 1952, a 10 MT device was detonated on land-surface at Eniwetok in Operation IVY, from which event only crosswind and upwind fall-out data were obtained. The vast downwind ocean areas over which the fall-out from such a large yield weapon occurs make a good determination of the fall-out pattern almost an impossible task if the shot is to be fired safely. It was not until the BRAVO event of the current CASTLE series that sufficient land areas downwind were contaminated by a very high yield surface detonation to permit a reasonably accurate delineation of the fall-out pattern from such a shot. The data obtained from surveys of these contaminated islands provides an invaluable tie-point for the scaling of radiological effects from high-yield weapons, even as the JANGLE-S event has provided just such a tie-point for low yield weapons.

In order to gain an understanding of the nature of the fall-out problem, one must recall that the available gamma activity from the detonation of a nuclear device is about 300 megacuries per kiloton yield at a time of one hour after the burst; and that for a surface burst, a large amount of this activity (20 to 80 per cent) can be expected to fall out within contours enclosing radiation intensities of military interest. Just where this activity is eventually deposited depends upon a great many factors, the most important of which is weather, wind direction in particular. Other important factors are the form and height of the radioactive cloud, and the particle size distribution of radioactive matter within the cloud. These factors determine, in a large measure, the ultimate destination and the time of arrival on the ground of a given particle within the bomb cloud.

One can obtain a feel for the radiation intensities involved from the fact that one megacurie of fission products per square mile uniformly distributed over a flat surface, produces a radiation intensity of about four roentgens per hour measured three feet above that surface. As an illustrative example, if the roughly 150 megacuries of activity at H+1 hour that is apt to fall out from a 1-kiloton surface burst, is distributed uniformly over a one square mile area, the radiation intensity three feet above this surface at H+1 hour would be about 150 x 4, or 600 roentgens per hour. For uniform distribution of this same activity over larger areas, the radiation intensity would be reduced proportionately. We see immediately that a 10 megaton surface burst could, by the same reasoning, cover a 10,000 square mile area with a radiation intensity of 600 roentgens per hour at a reference time of H+1 hour, if uniform distribution of the contaminant over that area and at that time could be assumed. Fortunately, this is not the case, since fall-out time may require from one to twenty or more hours over some parts of this vast area, during which time the radioactive particles still airborne are decaying and expending their energy harmlessly in the atmosphere. Also, distribution is not uniform, and some relatively small areas are very heavily contaminated, while much larger areas are lightly contaminated. Nevertheless, very large supralethal contaminated areas can be expected to result from such a detonation, and the fact that up to 90% or even more of this supralethal area can be outside the range of blast and thermal effects from the explosion makes fall-out contamination a primary rather than a bonus effect for surface-burst nuclear weapons.

Rather extensive and somewhat complex changes in the mechanism of fall-out may be expected if the weapon is burst on deep water rather than on a land surface; or again, if the weapon is burst on shallow water over a clay mud bottom. For the deep water case, one would expect the contaminant to be distributed as a very fine aerosol mist, and that as a result the lower dose rate contours would be larger and the high dose rate contours smaller than for a corresponding burst over a land-surface. Conversely, for a burst over wet clay mud, much of the contaminant is likely to be entrained in the mud and could be expected to fall out locally, resulting in large local high dose rate contours and smaller low dose rate contours than for the dry land case. In each case, however, the same amount of contaminating activity is available, and only the distribution of this activity is likely to vary to any great extent.

The rate of decay of the fission product contaminant follows quite closely the approximate exponential relationship

$$I = kt^{-1.2}$$

where I is the intensity at time t and k is a constant and can be taken as the dose rate at H+1 hour. This relation is useful for predicting the decay of the contaminant in most cases for which there is no serious dilution of the fission product contaminant by neutron-induced activity, either in bomb components or in soil or other materials contacted by the fireball. In some cases, however, the contribution to the residual activity by neutron-induced contaminants such as Na^{24} or Np^{239} may equal or even exceed the fission product activity for brief periods. This introduces perturbations into the slope of the decay curve which may cause the exponent of t to vary for brief periods of time between -0.8 and -2.0. In general, however, the over-all deviation from the basic fission product decay slope of -1.2 is not expected to be very great over long periods of time. This decay rate is such that the intensity at one hour is reduced by a factor of ten by H+7 hours, and by a factor of 100 after two days.

One can see from the number of variables involved that the fall-out problem is in practice largely a non-definitive one. An unexpected (and yet very possible) change in any one of a number of these variables can change the fall-out picture radically. However, it is possible to define the extent of the danger areas involved within rather broad limits for the 15 MT yield of the BRAVO event, and to indicate the manner in which corresponding danger areas can be predicted for other yields in the megaton range, and for other wind conditions. Magnitudes of areas involved are not likely to be altered greatly by changes in variables other than yield; specific locations of these areas, however, are more uncertain. It must be emphasized that detailed analysis of this problem is still in progress, so that the material presented in this paper, although the best that is currently available to the HQ, AFSWP, may later be subject to modification. The importance of the problem is such as to make this presentation of an interim analysis desirable at this time.

This paper is limited to coverage of the immediate, short-term problem, which is of paramount interest in military operations. No consideration is given at this time to the long-term effects of external radiation upon longevity, nor to internal radiation health hazards following inhalation or ingestion of radioactive materials.

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II. FALL-OUT CONTOURS FOR A 15 MT LAND-SURFACE BURST

The only true land-surface burst fired by the United States whose total residual radiation contours have been adequately documented to the present is the JANGLE surface shot. However, uncertainties in the postulated mechanism of fall-out even for small yield bursts, and unknown variations between fall-out mechanisms for small yield and very large yield devices, allow little confidence to be placed in scaling of data from the 1.2 KT JANGLE experience up to the megaton range. Consequently, the approach followed in this paper has been to analyze the data which constitutes fragmentary documentation of the CASTLE BRAVO shot in the light of postulated fall-out mechanisms and scaling relationships derived from extensive study of JANGLE information.

CASTLE BRAVO was fired on the surface of a coral reef, and gave a yield of approximately 15 MT. Although coral is not a typical soil material, nor is a water-level reef surface truly comparable to dry land, this particular shot provided a unique opportunity to gain at least partial documentation of fall-out radiation effects from a large yield weapon burst under conditions at least approximating a land-surface detonation. This is so because at least a portion of the downwind fall-out pattern from this shot covered several atolls and islands, thus enabling radiological surveying and fall-out sampling to be carried out. This cannot be accomplished with comparable effectiveness in the case of over-water fall-out, which characterized the other large yield shots of the CASTLE and IVY test series.

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Furthermore, the other high yield detonations of the CASTLE operation were water-surface bursts (barges); whereas the IVY MIKE shot, although a land-surface burst, lacked downwind fall-out documentation.

Since fall-out contours depend in large measure upon the active particle size distribution, and since this distribution in turn is related to the nature of the surface materials contacted by the fire-ball, CASTLE BRAVO might not be expected to behave exactly as a typical land-surface burst on other than coral sand. However, the fall-out pattern from a contaminating nuclear burst is essentially unique for that particular detonation, depending very strongly on the particular meteorological conditions existing at the time, so that only an approximate generalization of fall-out patterns and areas is being attempted in this paper. Furthermore, very preliminary data to date suggest that the magnitude and extent of the downwind fall-out pattern may not be overly dependent upon the type of surface involved. For these reasons, CASTLE BRAVO will be utilized as a representative land-surface shot at approximately 15 MT for purposes of downwind fall-out scaling in this report.

Residual radiation effects in the immediate upwind and crosswind vicinity of ground zero appear to be more highly dependent upon the rapid fall-out of relatively large particulate material from the turbulent mushroom cloud and upper stem. Since the amount of relatively large particulate material is vastly decreased in water-surface shots, it is possible that the fall-out effects about the ground zero region are more sensitive to the type of surface involved than are the fall-out effects far downwind. Since the CASTLE BRAVO shot may be characterized as a hybrid between a land-surface and a water-surface shot, probably most like the former, its ground zero radiation data may not be very representative of a true land-surface detonation. For this reason, the IVY MIKE shot has been used as the primary source of data for scaling of radiation effects in the ground zero region. IVY MIKE was detonated at approximately 10 MT at the tip of an island on a coral reef.

The downwind fall-out contours constructed for CASTLE BRAVO were based essentially upon survey data taken on the islands involved in the fall-out region. (Reference 2). After construction of contours based on this approach, predicted fall-out contours based on meteorological data (from R. E. Maynard, verbal communication) were then compared and minor adjustments were made to maintain consistency with both approaches.

Since the CASTLE BRAVO survey data consisted of a considerable number of different dose rate surveys taken at different times, the various data had to be normalized to some reference time before downwind dose rate contours could be constructed. For this purpose, consideration had to be given to the decay characteristics of the residual gamma radiation.

A. <u>Decay of Gamma Dose Rate with Time</u>

In general, gamma radiation from fission products is said to decay as $t^{-1.2}$. This analytical representation permits easy manipulation of data, but it provides only a statistical fit to the best data. It would not be applicable to the decay of gamma dose rate in a field situation if, during fall-out, there were considerable fractionation of the various fission products with distance, or if there were considerable in situ physical decay due to weathering effects or, if there were considerable radiation from neutron induced radioactivity.

Preliminary collected evidence to date has not suggested important fission product fractionation with distance at CASTLE. Also, the weather during the two weeks following BRAVO shot was dry, with little or no rain; and fairly large islands probably show little change in average gamma dose rate due to the effect of ordinary trade winds. Induced activities, on the other hand, probably were quite important in this shot, as is suggested by the marked departure from $t^{-1.2}$ decay measured for samples of fall-out material followed in the laboratory and also measured with fall-out time-intensity dose-rate meters in the field. The importance of induced activities is further suggested by preliminary radiochemical analyses and cloud samples.

Preliminary radiochemical data from cloud samples taken by AFOAT-1 (Dr. W. D. Urry - verbal communication) were used to determine ratios of various neutron induced activities to the number of fissions occurring in BRAVO shot. [redacted]

[redacted]

[redacted] Then, knowing the characteristic decay times of the radionuclides involved and assigning an appropriate gamma energy per decay, the gamma emission of the neutron induced activity was plotted against time. Since this has been done previously for fission fragments by Heiman (Reference 5), the relative gamma activities from induced components and from fission products themselves were then plotted together against time; and the results were added to give total fall-out gamma activity against time. This is seen in Fig. 1, where the activities are normalized to 1 r/hr at one hour (H+1).

This total activity curve may then be compared with a total activity predicted by $t^{-1.2}$ decay. In Fig. 1, $t^{-1.2}$ decay is represented by two curves; one normalized to the calculated total decay at H+1 hr., and the other normalized at H+240 hr. This latter time represents the approximate time that the majority of the surveys used in establishing the BRAVO fall-out patterns were made, and this $t^{-1.2}$ curve may be termed the "nominal" $t^{-1.2}$ decay for use with contours presented in this paper. It can be seen that at least during times of greatest interest (less than 1000 hours) the "nominal" and calculated activities are within approximately 25% of each other, (i.e., the calculated curve predicts gamma activities at H+1 that are only 78% of those predicted by extrapolation of the "nominal" curve.) Because of the much greater ease with which it can be manipulated, the nominal curve can probably be used with reasonable accuracy to represent the gamma activity of fall-out material when the curve is

[redacted]

normalized to data measured at approximately two days, or at about one to one and one-half weeks.

Whichever decay curve is used, it can be seen from Fig. 1 that the gamma dose-rate is most intense in the first few hours and decays most rapidly at early times. Between one hour and seven hours, the intensity falls about ten times. After two weeks, however, more than 80 days are required for another tenfold decrease in dose rate.

Actually, conversion of gamma activity curves to gamma dose rate over a wide area of fall-out is not exact, because gamma dose rate depends upon actual photon energy as well as upon total gamma energy emitted per radioactive disintegration. Decay schemes for many important nuclides involved in the fall-out gamma radiation are not known, and even when known, their conversion to gamma dose rate over a wide contaminated plane is laborious (see AFSWP 502A). In all probability, the calculated gamma activity versus time presents a reasonably accurate picture of the gamma dose rate in the fall-out field against time; and it will be so used in this paper.

In Fig. 2, the dose rate decay curves of Fig. 1 are integrated with time. From this figure, total integrated dose between any two times after H+1 hr. may be determined. The suggested method is to subtract the dose at the earlier time from the dose at the later time and then multiply by the dose rate at H+1 hr.

If the problem were to utilize the $t^{-1.2}$ decay assumption to determine the total dose between three days and seven days at a location where the "nominal" dose rate at H+1 was calculated to be 200r/hr., the solution could be found by the suggested method as follows. From

[redacted]

the $t^{-1.2}$ decay curve of Fig. 2, the dose at 168 hours (3.20r) less the dose at 72 hours (2.86r) leaves 0.34r. Multiplied by the nominal dose rate at H+1 (200r/hr), this would give an answer of 68r to the problem.

In a similar fashion the "calculated curve" of Fig. 2 might be utilized when the "true" dose rate at H+1 is known (i.e., 78% of the nominal dose rate at H+1, as determined from Fig. 1). It appears that in the worst possible case an error of the order of 35% might be introduced by utilizing "nominal" H+1 dose rates with $t^{-1.2}$ decay rather than utilizing "true" H+1 dose rates with the calculated decay curve.

The nominal $t^{-1.2}$ method is therefore probably sufficiently accurate for purposes of this analysis. Because of its greater ease of manipulation, it is recommended for general application with the isodose-rate contours presented in this paper. For greater ease of analysis by the nominal $t^{-1.2}$ method, isodose-rate contours presented in the figures of this report are labeled with their "nominal" H+1 dose rates ($\frac{1}{0.78}$ = 1.28 times the "true" H+1 dose rates).

The general application of Figs. 1 and 2 should be noted. In the construction of the calculated decay curve in Fig. 1, [redacted] fractionation of the fall-out sample is not severe. [redacted]

B. Idealized Downwind Fall-out Contours for 15 MT

The actual survey data from CASTLE BRAVO was assembled and corrected to a reference time of H+1 hr. according to the "nominal" $t^{-1.2}$ decay noted in Part A. These numbers were then placed in their proper locations on a map of the fall-out area and contours were drawn as shown in Fig. 3. The data relied upon most heavily for this purpose were the surveys taken from approximately seven to eleven days following shot time (Reference 2).

Through each atoll a gradient could be placed, indicating increasing H+1 dose rate contours in a northerly direction. By connecting gradients made in this fashion on those few islands from which data were available, rough contour lines for "nominal" H+1 hr. dose rates could be drawn. It was assumed in the absence of any data points on the northern side of the fall-out pattern that a rough symmetry existed, and the contour gradients therefore were duplicated on the northern side of the pattern.

The region of the maximum dose rate could not be definitely determined from the data at hand, and might have been at any distance within a few miles to the north of the islands involved in the pattern. In an effort to be conservative in drawing the areas of the dose rate contours, the maximum dose rate was assumed to have been delivered

[redacted]

just slightly north of the measured points on the islands. In this fashion, the center line of the fall-out pattern ran very close to the northern aspects of the islands, and the resultant fall-out contours were drawn as narrow as the data would permit, assuming symmetry on the northern and southern sides of the center line.

A later comparison of this portion of the contours with predictions of fall-out based on meteorological data suggested that the highest dose contours might have been farther north of the islands than was drawn in the overlays. This would have resulted in a more northerly position of the center line of the fall-out pattern and a consequent increase in the width and thus in the areas of the downwind contour zones. Thus the meteorological data suggest that the contours as drawn from the radiological survey information may be somewhat conservative. Furthermore, the downwind extent of the lower dose contours was poorly documented by data available. As a further conservative approach, the contours were closed off in distance as short as was consistent with the one or two survey points available for downwind distances.

The resultant "nominal" H+1 dose rate contours that were drawn are indicated in Fig. 3. It will be noted that the contour lines overlay several atolls on the southern side of the pattern. It is at these points that the contour lines are most firmly "pegged". It can be seen that the far downwind extent of the contours is documented only by the readings from Bikar Atoll and Utirik. The data

[redacted]

on fall-out radiation in the immediate vicinity of ground zero were scanty on the BRAVO shot, and the downwind fall-out contours are not closed about ground zero.

The areas of the downwind contour zones are measured by planimetry. [redacted] This is felt to be a reasonable figure in the light of fall-out mechanisms as presently understood; but it also allows somewhat larger contours to be constructed without demanding an unreasonable amount of deposited fission product. Accordingly, as previously noted, the contours as drawn may still be thought of as conservative in that they are probably smaller than those that actually existed at BRAVO.

It should be noted that since in actual fact fall-out does not commence at distances downwind until several hours have elapsed, the "nominal" H+1 dose rate contours shown in Fig. 3 do not actually exist as such at that time. The dose rates at the time of actual fall-out would be lower than indicated on the figure and could be determined from Fig. 1 for each appropriate time of fall-out along the downwind pattern. The H+1 hr. dose rate contours do serve as reference contours for dose rate and integrated dose calculations, however, and thus they are presented in that form.

Although the weather data from BRAVO indicate that wind velocities were such as to result in a very narrow fall-out band downwind with less wind shear of the mushroom cloud and stem than would be expected with average weather conditions and that there was a superimposed fall-out from the stem and the mushroom, the contours may still be taken as reasonably representative of a land-surface shot of 15 MT. The effect of a greater wind shear would be to broaden the area of the fall-out pattern and to reduce somewhat the intensity of the isodose lines. However, as previously noted, the contours as drawn are somewhat conservative and narrow based on the data from BRAVO, and consequently they may be taken as reasonably representative for scaling purposes.

In order to generalize the contours from BRAVO for scaling purposes, an "effective wind" is assumed. A single hypothetical line of wind flow is assumed which gives rise to the fall-out pattern most nearly like that which in fact occurs. This hypothetical wind flow is then straightened out in the major downwind direction, where it can be represented by a single wind of constant velocity, the so-called "effective wind". This is not realistic in fact; but since local meteorology is too variable to treat analytically in a general case, this approach permits idealized contour shapes to be drawn. If an "effective wind" is assumed for BRAVO, the effect is to straighten out the contour lines of Fig. 3 about a single "effective wind" vector. This results in contours as shown in Fig. 4, and it is these generalized contours that can be conveniently used for scaling purposes.

C. Idealized Ground Zero Fall-out Contours for a 15 MT Land-Surface Burst

As previously noted, the best data concerning residual radiation levels in the vicinity of ground zero derive from IVY MIKE. Here, reasonably good crosswind fall-out data and some upwind data in the region of ground zero were collected from lagoon and island stations by USNRDL. These have been compiled and analyzed in WT-615, and from this they have been smoothed for general scaling purposes by AFSWP (Reference 3). In general, the IVY data are consistent with the qualitative results of Operation JANGLE, and using the scaling method to be outlined in Chapter III of this paper, the quantitative comparison is also good.

Accordingly, the scaling method of Chapter III has been utilized to scale the smoothed IVY MIKE data to 15 MT. The general pattern of "nominal" H+1 dose-rate contours about ground zero can then be drawn for 15 MT. This is shown in Fig. 5. Fig. 5 is then comparable to Fig. 4 for the downwind fall-out pattern, except that the scale is different.

[redacted]

Some uncertainty remains in the use of Fig. 5 to represent the idealized ground zero contours, because the fragmentary data taken near ground zero on BRAVO do not indicate as extensive a fall-out pattern about the detonation site as was seen with IVY MIKE. Although the earth surface composition was not identical in the two cases (p. 8), the difference may not have been sufficient to account for the variation in the ground zero contours. It is possible that variations of this order in the ground zero pattern will be encountered characteristically with land-surface detonations.

D. Estimation of Actual Dose Received in the Fall-out Pattern

As noted in Part B of this chapter, the nominal H+1 isodose-rate contours are very desirable for basic reference purposes, but they lack physical meaning. In order to estimate actual radiation dose received during some interval after burst time, the time of actual fall-out must be taken into account. For CASTLE BRAVO an effective wind of about 15 knots may be shown to give a reasonable fit with the estimated or measured time of fall-out at various distances downwind. This is based on the assumption that the time of fall-out can be taken roughly as downwind distance divided by effective wind velocity.

Since the rapid lateral spread of the mushroom cloud at early times results in a fall-out particle source of finite volume (perhaps 60-70 miles in diameter for a 15 MT land-surface burst), some fall-out will begin at earlier times than predicted by the above approach; but by the same token fall-out will continue over an appreciable time,

[redacted]

so the "effective" time of fall-out for purposes of integrating dose may be reasonably represented in this simple way.

When this approach is compared with best estimated times of fall-out for BRAVO, where actual wind shears did exist and no effective wind simplification was used, then the following comparison can be made:

Table I

Time of Fall-out Arrival for BRAVO

Distance downwind (mi.)	15	46	74	103	148	210	270	310	330
Estimated fall-out time (hr)	1*	4	6	7*	8*	13	15	18*	20
Distance/effective 15 knot wind	1	3	4	6	9	12	15	18	19

*These times are derived from actual observation, the reference times for which are not well standardized.

In order to estimate dose it is only necessary to apply the method of Part A, using Figs. 2 plus 3, 4, or 5. Dose may be estimated from fall-out or from some arbitrary time of entry to infinity or to some other time of interest. To do this, one goes to Fig. 2 to determine the dose received over the period of interest (which may begin with fall-out, as found in Table I) at a position where the "nominal" H+1 dose rate is 1r/hr. Then Fig. 3, 4, or 5 may be used to determine the actual "nominal" dose rate at H+1, and the final answer is found as in the example on pages 11 and 12.

An example of how this method may be used to construct actual total dose contours at an arbitrary reference time has been worked out using

[redacted]

Fig. 3 and Table I. H+50 hrs. was selected as a reference time of some pertinence, because by that time all parts of the downwind fall-out pattern have had sufficient time to accumulate significant dosages, and yet the poorly evaluated effects of biological recovery from radiation damage have not yet become important in altering the criteria of radiation response from the acute dose situation, where they are known with greatest confidence (see Chapter IV). Furthermore, although infinite residence within a fall-out pattern is not a realistic assumption, neither is evacuation in a few hours a valid consideration to apply to a large population within a vast contaminated area and 50 hours, although an arbitrary figure, is of real interest in this regard.

For illustrative purposes, however, the fall-out-to-H+50 hr. dose contours will serve to demonstrate that, because fall-out occurs at later times downwind than it does near ground zero, the effect on the shape of the total dose contours is to make them shorter than isodose-rate contours, wider at the head end, and narrower at the downwind end. This is because fall-out-to-reference time is a longer interval close-in than it is far-out, resulting in longer integrations of dose rate with time at the near portion of any given isodose-rate contour than at the downwind portion. An example of the relative shapes of isodose and isodose-rate contours from fall-out is seen in Fig. A, and also in Fig. 6, where isodose contours from fall-out to H+50 hrs. are superimposed on the isodose-rate contours of Fig. 4.

It can readily be seen that isodose contours for any time interval commencing after all fall-out is completed will be of the same shape as the isodose-rate contours.

[redacted]

[redacted]

III APPROXIMATE SCALING OF FALL-OUT CONTOURS WITH YIELD

It has been pointed out that fall-out contours for any contaminating burst are highly dependent upon ambient conditions characterizing the detonation. At the same time, the assumption of an effective wind permits generalization of fall-out contours that in all probability will not differ widely from the actual contamination pattern in any given case, and the "idealized" pattern allows reasonable expectations of area and extent of residual radiation effect to be made for planning purposes. It is highly desirable to generalize one step further, if possible, so that values of fall-out contour parameters derived from an experience at a fixed yield and associated with a given effective wind may be scaled to other yields and possibly to other effective winds. This allows at least a qualitative adjustment in the generalized fall-out patterns to be made for actual variations in ambient winds.

A. Method of Scaling

Perhaps the most promising method for scaling generalized contamination patterns presently available is that developed by USNRDL (Reference 4). This method is based essentially on five primary assumptions, all of which are consonant with data gathered from actual experience:

(1) The total amount of fall-out radioactivity present in the cloud is dependent on yield; or more particularly, on total fission yield.

[redacted] [redacted]

(2) The height and linear dimensions of the cloud both scale in the same way with yield.

(3) For a given soil, the relative size distribution of radioactive particles is independent of yield.

(4) The relative spatial distribution of active particles of any given size is independent of yield.

(5) The rate of fall-out of active particles depends only on particle size. (The altitude from which fall-out commences may also be important for large particles, which fall according to aerodynamic principles; i.e., particles with diameter greater than 250 microns.)

From these assumptions, certain general scaling laws may be derived:

(1) For a constant effective wind, linear parameters of isodose-rate contours scale as yield to an exponential constant (i.e. W^a) and the dose-rate intensity of a given contour simultaneously scales in the same fashion (W^a). From this, contour areas can be seen to scale as W^{2a}. This scaling preserves contour shapes with changes in yield.

(2) At constant yield, experience with mass fall-out from high explosive tests shows total area within a given contour to be quite insensitive to changes in effective wind. Thus, if the downwind extent of a given contour scales as wind velocity to an exponential constant (i.e., U^b), then the crosswind extent of the same contour scales inversely (i.e., U^{-b}). This results in longer and narrower contours with higher effective winds.

Since a basic aim of the NRDL scaling method is to preserve material balance and thus to retain equivalent fractions of total fission product yield within a given fall-out contour at all yields, the exponential constant, a, in the above scaling equations is set at 1/3. Analyses of bomb clouds and radiation fall-out contours at JANGLE, the cloud and radiation contours near ground zero from IVY MIKE, and mass fall-out contours from HE tests suggest that the exponential constant, b, also may be taken as 1/3. This results in the scaling laws for fall-out radiation contours that will be used in this paper, namely:

(1) At constant effective wind velocity, linear parameters of isodose-rate contours scale as the cube root of yield (actually as the cube root of fission yield), and areas scale as the two-thirds power of yield. At the same time, the isodose-rate intensities of the respective contours scale also as the cube root of yield.

(2) At constant yield, areas within isodose-rate contours probably remain constant, but downwind extent varies as the cube root of wind velocity and crosswind extent varies inversely as the cube root of wind velocity. For winds less than about five knots, dimensions become dependent upon maximum cloud growth; but effective winds less than five knots will not be seen realistically with high yield devices, whose clouds ascend to great altitude.

The scaling described in (2) above depends, of course, on variations in effective wind only. The effect of actual wind shears will be reflected somewhat in the effective wind, but considerable shearing probably will increase areas of low isodose-rate contours and decrease areas of high isodose-rate contours in a manner that cannot be easily represented.

As an example of the use of these scaling laws, suppose that a given isodose-rate contour from an 8 MT surface burst with a 15 knot effective wind reads 100 r/hr normalized to H+1, and its downwind extent is 116 miles. Find the downwind extent of the scaled contour and its scaled intensity for a 1 MT burst with a 30 knot effective wind.

(1) The downwind extent of the 1 MT contour is $(\frac{1}{8})^{1/3} \times 116 = 58$ mi. with a 15 knot wind.

(2) The scaled intensity of the 1 MT contour is

$$(\frac{1}{8})^{1/3} \times 100 = 50 \text{ r/hr at H+1.}$$

(3) The downwind extent of the 1 MT contour with a 30 knot effective wind is $(\frac{30}{15})^{1/3} \times 58 = 73$ mi.

Thus, the scaled contour has an intensity of 50 r/hr at H+1 and extends 73 miles downwind.

B. <u>Assumed Contour Shapes for Scaling</u>

From both JANGLE and high explosive experience, NRDL generalized a contour shape for fall-out patterns based upon the effective wind concept. About ground zero is a so-called "ground zero circle" (GZ circle) formed soon after the detonation from rapid fall-out of relatively large particles. It can be defined by its radius and by the downwind displacement of its center from GZ, as can be seen in Fig. 7. The downwind pattern of fall-out proper can be defined by its downwind extent (major axis) and its crosswind extent (minor axis); although the downwind extent must properly be corrected for wind shear in any actual case.

As noted in Part C of Chapter II, and in Fig. 5, the IVY MIKE fall-out data can be seen to be generally consistent in the region near GZ with the contour shapes predicted by the NRDL "GZ circle". Consequently, it appears warranted to utilize the NRDL "GZ circle" to characterize the generalized fall-out contours from very large yield surface bursts.

As seen in Figs. 3 and 4, the CASTLE BRAVO downwind isodose-rate contours are not truly elliptical in shape as they are drawn. However, from Part A of Chapter II, it can be seen that the exact shapes of the downwind portions of the contours are somewhat arbitrary; further, it must be recalled that the contours drawn have been idealized about an effective wind. Also, if the downwind extent of the patterns as drawn is taken as the major axis of an ellipse and the crosswind extent is taken as the minor axis, then the area of the comparable ellipse generally is less than 15% greater than the area of the actual isodose-rate contours as planimetered. Thus, it appears reasonable to use the NRDL-type downwind elliptical approximation for generalized representation of downwind fall-out, even for large yield detonations.

C. <u>Applicability of Contour Shapes and Scaling</u>

It is important to bear in mind that the contour shapes and scaling discussed in this paper apply only to surface bursts, and primarily to land-surface bursts. As discussed earlier, water-surface bursts may scale somewhat differently; and in particular, the "GZ circle" portion of the idealized general scaling contour may be much smaller, and may be displaced farther downwind than is the case with land surfaces. At present, no definitive data is available regarding this effect.

Underground bursts may scale in a fashion similar to land-surface shots, but the parameters of the basic contours will be different. True underground bursts of very large yield weapons are not apt to be encountered operationally, however; hence, no further discussion of that situation will be attempted here.

True air bursts, where the fireball radius does not intersect the earth's surface, will not produce significant local fall-out areas of high intensity. However, where air bursts are detonated at such altitudes that there is considerable intersection of the fireball with the ground, then a situation intermediate between a "true" air burst and the land-surface burst discussed in this paper will obtain. As a rough rule of thumb, it may be estimated that the fraction of total fission products that will fall out within the local radiation contamination contours will be about equal to the fraction of fireball subtended by the surface. [redacted]

In reality, the fireball diameter of weapons with yields in the megaton range is so great that even bursts fired at several hundred or even a thousand feet above the surface, in the case of the highest yields, can probably be thought of as surface bursts from the standpoint of residual radiation contours. Furthermore, there are indications that, because of diminution of blast pressures at the low ambient pressures associated with even moderate scaled heights of burst for "super" weapons, even low blast overpressures may be maximized by surface bursts in the case of very large yields. Consequently, surface bursts of weapons of megaton yields may be the most desirable situation in many operational cases, and in such instances the idealized fall-out contours presented in this paper would be directly applicable.

D. Basic Numerical Parameters to be Used in Scaling Isodose-rate Contours.

The idealized 15 MT land-surface burst contour discussed in Part B of this chapter is probably the most valid reference contour for use in scaling in the megaton yield range. It will be recalled that this pattern utilizes CASTLE BRAVO data for its downwind ellipse and IVY MIKE data for its GZ circle radius. The downwind displacement of the GZ circle, a minor parameter, is scaled up from JANGLE "S" by the method of Part A of this chapter. It is scaled according to total yield [redacted] because this particular parameter appears dependent primarily upon cloud heights and dimensions rather than upon total amount of fission, which is the most critical variable for the scaling of the other contour parameters.

Basic JANGLE data is generally disregarded in determining the numerical values of parameters for contours in the very high yield range. Very low dose-rate contours from JANGLE are available with less confidence in their accuracy than for the higher dose-rate contours, since they are based on air survey data; yet they are important in scaling to moderate dose-rate contours at high yields. Furthermore, the mechanisms of fall-out at low yields (JANGLE = 1.2 KT) and at high yields may be sufficiently different so that scaling idealized JANGLE data over a yield range of greater than 1,000 times may be unsatisfactory. In fact, the actual scaling of JANGLE data to 15 MT [redacted] results in high dose-rate contours that are too short and as much as 10 times too small in area when compared with the results shown in Fig. 3 or 4; and only at H+1 hour isodose-rate contours below about 200 r/hr do the two predictions agree closely.

For the above reasons, basic numerical parameters derived from more detailed contour charts of the same types as Figs. 3, 4, and 5 have been utilized for reference numbers in this paper. In Figs. 8 and 9, these linear parameters are presented graphically. These figures may be used to scale idealized isodose-rate contours (normalized to H+1 hour) of the type of Fig. 7 for yields in the megaton range and above.

[redacted]

In Fig. 10 the areas within the downwind contours corresponding to the linear parameters listed in Figs. 8 and 9 are presented. The areas shown are derived from actual planimetry of the isodose-rate contours, but as discussed in Part B of this chapter, they are in most cases less than 15% smaller than the areas predicted by assuming the downwind and crosswind extent of the contours to be equivalent to the major and minor axes, respectively, of an ellipse. This is a small error when compared with the over-all accuracy of the idealized contour scaling method.

It should be noted that the isodose-rate intensities indicated in Figs. 8, 9, 10, and 11 are "nominal" H+1 hour intensities, as discussed in Part A of Chapter II. They may be utilized with the "nominal" $t^{-1.2}$ decay curves discussed in that part for reasonably accurate calculations of dosages. Greater accuracy may be achieved by calculating "true" H+1 hour intensities as noted (78% of "nominal" intensities) and then utilizing the calculated total activity curves of Figs. 1 and 2. "True" H+1 hour intensities would also be used with any other total activity curve that might be calculated [redacted]

DOE b(3)

E. Effect of Weapon Design Upon Fall-out Scaling

It is important to realize that although figures in this paper are scaled according to total weapon energy release (yield), only fission energy release was used for actual calculation of data.

[redacted] [redacted]

Consequently, the numerical scaling based on Fig. 8, ff. will be strictly valid only for thermonuclear weapons of the IVY MIKE and CASTLE BRAVO type. However, in general, other types of thermonuclear weapons are expected to give nuclear contamination of the same order

[redacted]

DOE
b(3)

F. Scaling of Total Dose Contours

In Part D of Chapter II, a method of constructing total dose contours was discussed, and Fig. 6 and Fig. A were given as examples. However, scaling of total dose patterns with yield cannot be accomplished accurately with the ease with which one may scale isodose-rate contours (Part B of Chapter III). This is so because total dose contours are calculated on a basis that includes time of fall-out at various distances downwind. Figs. A and 6 were constructed in this fashion, and from a similar but more detailed figure, the data of Fig. 11 were derived.

To scale the data of Fig. 11 directly to other yields by the USNRDL scaling method (Part B of Chapter III) would therefore imply scaling of effective wind as well as of yield. If winds remain constant, scaled dose areas for yields greater than that applying to Fig. 11 would be too large. Also, the downwind extent of the contours would be too great, because Fig. 11 implies integration of dose beginning at times earlier than fall-out arrival time at scaled distances downwind. Similarly, scaling to yields less than 15 MT with constant effective wind would result in scaled areas and downwind distances that are too small.

Accurate construction of total isodose contours would require re-application of the method of Part D of Chapter II in each case, employing the scaled parameters based on Figs. 8 and 9 in place of Figs. 3, 4, and 5, as used in that Part. This technique is laborious, however, and useful approximations probably can be calculated using Figs. 11 and A (or similarly calculated figures based on 15 MT) and the scaling method of Part B of this chapter. Examples of scaling from a figure similar to Fig. A and from Fig. 11 are given in Table II, and for the 60 MT case the properly calculated downwind extent and contour area (using the method of Part D, Chapter II) are given for comparison. The simplified approximation based on Figs. A and 11 is seen to be about as good as the best expected accuracy from the idealized scaling method presented in this paper.

Table II

Total Isodose Contour: 500r from Fall-out to H+50 Hours

Yield (MT)	15	1	10	60	* 60
Downwind extent (mi)	180	52	152	340	(307)
Crosswind axis (mi)	40	12	34	70	
GZ circle radius (mi)	11.5	3.85	9.7	21	
GZ circle displacement (mi)	3.5	1.2	3	5.75	
Area (mi^2)	5400	470	3880	17,900	(16,250)
Area of true ellipse (mi^2)	(5650)	(491)	(4055)	(18,700)	

* Using Part D, Chapter II.

G. Examples of Scaled Fall-out Contours

Fig. 12 demonstrates on a single scale examples of idealized fall-out contours for weapons of several yields, all for 15 knot effective wind. The data from Figs. 7 - 11 and the scaling method of Part B of this chapter were utilized to scale the parameters. The scaled parameters used are listed in Table II (isodose contours) and Table III (isodose-rate contours).

[redacted]

Table III

Nominal Isodose-rate Contours: 500r/hr. at H+1

Yield (MT)	15	1	10	60
Downwind extent (mi)	188	49	152	384
Crosswind axis (mi)	37.2	10.7	32	64
GZ circle radius (mi)	7.9	1.9	6.55	15.1
GZ circle displacement (mi)	1.22	0.41	1.04	2.1
Area (mi^2)	4900	340	3360	17,620
Area of true ellipse (mi^2)	(5500)	(412)	(3820)	(19,300)

[redacted]

[redacted]

IV. DEFENSE AGAINST THE FALL-OUT HAZARD*

To evaluate the problem of passive defense against the external radiation hazard cause by the gamma radiation from the bomb fall-out, it is necessary to consider a variety of factors which affect the problem. Among these factors are the effect of shielding, of decontamination, of radioactive decay, of evacuation and of the biological recovery from and repair of, acute radiation damage.

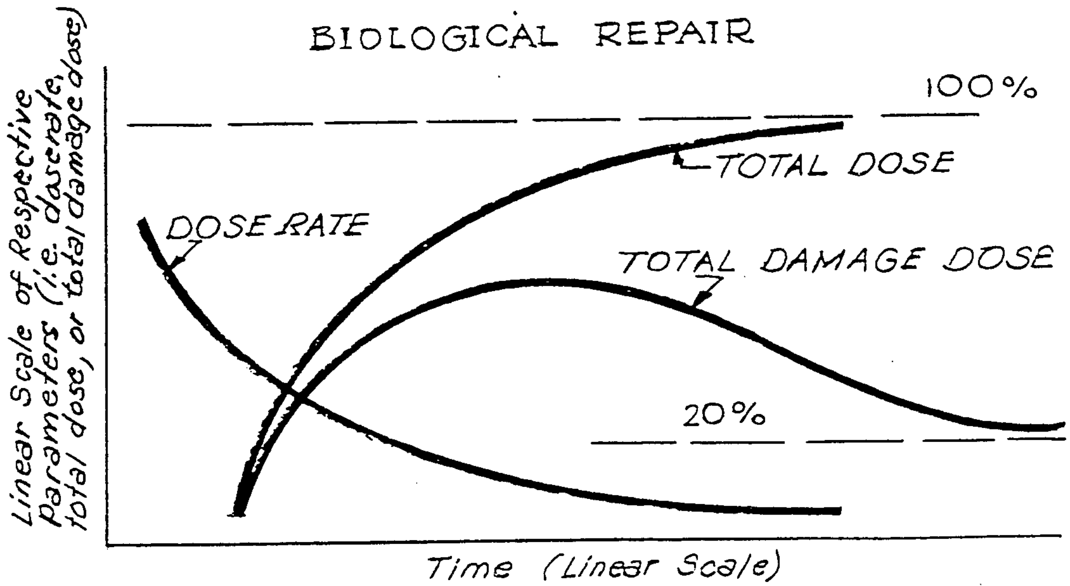
The mathematical treatment employed in the preparation of the tables found in this Chapter is set forth in detail in Appendix A. However, a qualitative description of how the various factors enter into the problem and play their part will be given here for the convenience of the reader who does not care to work through the mathematics of the problem in detail. If the reader will keep in mind two parameters it will assist in understanding how the situation is influenced. These parameters are the swift radioactive decay of the dose rate field, and the biological repair by and recovery of the human body with respect to external gamma radiation damage. That the human body does repair radiation damage cannot be denied. For example, the peacetime tolerance level for external X- and gamma radiation currently employed in the United States limits a worker to 0.3 roentgens per week. If we consider that such workers may work

*Throughout the discussion in this chapter, the assumption is made that the area making a defense against the fall-out hazard has not been directly hit by the bomb, or is outside the damage area due to blast and thermal effects.

[redacted]

50 weeks each year for a period of 20 years, we see that they could receive a total dosage of 300 roentgens over this period of 20 years. This dosage of 300 roentgens, if delivered over a time period of a minute or two would result in acute radiation effects in a considerable percentage of any given population. However, 300 roentgens delivered over a period of 20 years is considered to be sufficiently safe so that our peacetime tolerance levels have been established accordingly. The rate of biological recovery used in this paper is the same as that used by WSEG in Reference 1. It is to be noted that the numerical values of the parameters employed in this paper to represent acute radiation damage and the rate of biological recovery from radiation injury are near the upper limits. As a result of this, the tables of this chapter evaluating the effectiveness of protective measures are conservative from an offensive point of view and optimistic from a defensive point of view. However, the general nature of the conclusions that can be drawn from the material presented in this chapter would not be altered if one picked different numerical values for the above mentioned parameters. A general understanding of the effect of the various factors under discussion on the final result, namely the "damage dose", can be obtained by examination of the following qualitative sketch.

[redacted]



This sketch discloses that radioactive decay reduces the dose rate of the gamma radiation field as time increases. The total dose received by a person in such a field approaches a finite value at greater and greater times. The "damage dose" does not continue to increase with time but rather reaches a maximum and then dies away with time, and is taken in this paper to approach 20% of the total dose delivered at greater and greater times. Obviously the criterion pertinent to this problem is the maximum "damage dose" experienced by an individual in a gamma dose rate field, and this occurs at some finite time after he enters the radiation field. In the numerous tables which follow, this criterion has been applied and is the criterion tabulated and called "damage dose".

[redacted]

One additional factor should be kept in mind when reading the remainder of this chapter. The areas tabulated and referred to are those areas which are covered by the downwind tail of the fall-out pattern. These areas are found in Figs. 10 and 11. In general, they extend well outside the area damaged by the blast and thermal weapon effects.

A. The Effect of Shelter

To arrive at an appreciation of the damage to humans which would be caused by the heavy and extensive fall-out, it is instructive to examine three cases: persons in the open in rural areas, persons in the open in a city, and persons in the best average existing available shelter within a city. Excluding deep underground shelters of special construction, the best available existing shelters in a city to protect one against the fall-out gamma radiation are found in the basements of large buildings, within heavy masonry construction buildings, and on the middle floors of multistory buildings. Considering only the dosage delivered within two days after detonation, and using the physiological effects information and the average shielding factor information from Reference 1, the following net effects over the areas indicated can be computed.

[redacted]

Table IV

Areas for Various Effects from Dosage Accumulated up to H+2 Days After 15 MT Surface Detonation

		AREA IN SQUARE MILES FOR SITUATION INDICATED		
Minimum Damage Dose Within Area	Acute Effect	In Open In Rural Area	In Open In City (rural dose reduced to .7	In Best Aver.Shelter In City (rural dose reduced to .13)
205 r	SD/10	8,800	7,500	2,100
275 r	SD/50	7,600	6,200	1,500
370 r	LD/10	6,800	5,200	960
550 r	LD/50	5,100	3,900	440
630 r	LD/90	4,600	3,500	320

Note 1: Damage dose is taken as 0.9 of total dose delivered for this case.

2: SD/10 means sickness dose in 10% of personnel; LD/10 means lethal dose in 10% of personnel.

Table IV serves to point up the value of seeking and occupying the best available shelter should one be caught in the fall-out area. It is seen from columns 3 to 5 of the Table that the area within which persons would receive at least a sickness dose is decreased by a factor of four in this example chosen for illustration. It is also readily apparent from examination of the areas given in Table IV that the radiation hazard from fall-out is effective over a significant area even when the population takes the best cover which may be currently available to them. It is seen that even after staying in the best currently available radiation protection shelters in a

[redacted]

city* during the time from the beginning of fall-out until H+2 days that more than half of a city population can be expected to die from radiation effects over an area of four or five hundred square miles, and nearly all would be expected to die within an area of about three hundred square miles. An appreciation of how the areas listed in Table IV compare with the areas of some typical U.S. and USSR cities can be gained by inspection of Table IV in conjunction with Table V below.

Table V

Areas and Populations of Cities

City	Areas in Sq. Miles	Population
Rostov, USSR	24.3	500,000
Tulo, USSR	23.6	289,000
Gorkiy, USSR	62.0	900,000
Moscow, USSR	117	4,700,000
Denver, Colorado, USA	68.2	416,000
Detroit, Michigan, USA	142	1,850,000
District of Columbia, USA	69.2	802,000
New York, N.Y., USA	365.4	7,892,000

* The best currently available shelter protection factor in a city used in Table IV was taken from Enclosure "A" of the WSEG Report cited (Ref. 1). It was derived specifically for the city of Rostov, USSR, but is thought to apply equally well for other cities in Western Europe. For U.S. cities, variations from this factor are to be expected. For example, the inhabitants of Manhattan Island could protect themselves by a factor of several thousand by staying on the middle floors of the "sky-scraper" buildings which exist there. On the other hand, in a city such as Los Angeles, the population could probably not protect itself on the average by a factor as favorable as .13 in the now existing sheltered locations.

[redacted]

It should be borne in mind that the time up to H+2 days has been chosen in Table IV as a specific example solely for the purpose of illustration. Even though the radiation from the bomb debris dies away rapidly because of radioactive decay, vast areas are still contaminated to a dangerous level at H+2 days. The information in Table VI below illustrates this. Furthermore, all but a small part of the areas under discussion (Table VI) lie well outside of those areas which suffer damage from the blast and thermal effects of the weapon.

Table VI

Dose Rate Levels and Areas at Various Times for 15 MT Surface Detonation

Time After Detonation in Days	AREA IN SQ.MILES FOR RURAL AREA DOSE-RATE LEVEL INDICATED	
	More than 10 r/hr	More than 1 r/hr
2	2,700 mi^2	13,000 mi^2
4	700 mi^2	8,400 mi^2
6	100 to 200 mi^2	6,000 mi^2
10	within damage area	3,800 mi^2
14	within damage area	2,400 mi^2
23	within damage area	1,200 mi^2
42	within damage area	100 to 200 mi^2
71	within damage area	within damage area

B. The Effect of Decontamination

The problems involved in the decontamination of the city of Rostov, USSR, have been studied in considerable detail by the WSEG

[redacted]

(Reference 1). The WSEG study regards the results of the decontamination effort and the time and man hours involved as being applicable to many of the other cities of Western Europe. Since the population density of Rostov is relatively high (21,000 persons per square mile, while the highest urban population density in the United States in 1950 was that of New York City: 25,000 persons per square mile), and since a high population density favors decontamination, it can be assumed for the purposes of this paper that decontamination efforts in a United States city would probably not improve upon the results which have been estimated to be within the capacity of the population of Rostov for their city.

The WSEG group concluded that no city could be decontaminated with greater than 75% reduction in dose rate, and that in most potential target cities (this applies to cities in Western Europe) no more than 50% reduction in dose rate could be achieved by decontamination. The WSEG group also assumed that any decontamination effort would be directed toward the total city area, exclusive of any large tracts such as parks which do not have to be inhabited or traversed. In order to indicate what variable in duration of effort might reasonably be expected, two calculations were made by the WSEG group. One calculation was based on a set of assumptions which gave the population every possible advantage, including some which bordered on the inadmissable because of physical impracticality. The time for decontamination in this case was 2.2 days. A second calculation was

[redacted]

based on somewhat more realistic assumptions, but it still greatly favored the capability of the population to cope with the radioactive contamination in the city. In the WSEG report the decontamination effort was considered to have reduced the dose rates to 25% of those which would have prevailed without decontamination. Since Rostov is a city of relatively high population density, it was concluded by the WSEG group that the duration of the decontamination effort in Rostov may be taken as the minimum duration necessary in the other cities of Western Europe included in the target system considered by WSEG.

Table VII (below) was compiled for the purpose of this study by taking into consideration the results of the Rostov example, the fall-out areas involved, and the radioactive decay of the radiation field. The Rostov example assumes that the decontamination effort would reduce the radiation field to 25% of what it would have been had no decontamination been attempted. The starting times chosen for the example illustrated in Table VII were picked because at these starting times radioactive decay will not reduce the dose rate greater than down to 25% of what it was when decontamination started. In other words, it appears reasonable to stay in shelter, if such is available, at these early times until the radioactive decay has slowed down to this point. It should be appreciated that a reduction in dose rate brought about by decontamination is over and above the reduction caused by radioactive decay.

[redacted]

[redacted]

Table VII

Minimum Dosages Within Areas
For City Decontamination
15 MT Surface Burst

Case When Decontamination Takes 2.2 Days and Starts at H+2 Days

AREA	1000 mi^2	3000 mi^2	5000 mi^2	8000 mi^2
Damage dose after staying in best average shelter (fall-out time to H+2 days)	160 r	65 r	40 r	23 r
Damage dose during decontamination effort received by 66% of population which is engaged (H+2 days to H+4.2 days)	120 r	50 r	30 r	17 r
Total Damage dose received up to H+4.2 days	280 r	115 r	70 r	40 r
Acute biological effect	LD/1 SD/55	None	None	None

Case When Decontamination Takes 13 Days and Starts at H+6 Days

AREA	1000 mi^2	3000 mi^2	5000 mi^2	8000 mi^2
Damage dose before decontamination begins when in best average shelter (fall-out time to H+6 days)	240 r	110 r	60 r	30 r
Damage dose during decontamination effort received by 60% of population which is engaged (H+6 Days to H+19 days)	(No additional damage dose received due to biological recovery)			
Total damage dose received up to H+19 days	240 r	110 r	60 r	30 r
Acute biological effect	SD/25	None	None	None

[redacted]

Examination of Table VII discloses that even if decontamination were successful any time during the period of approximately 20 days following the detonation, the persons residing in large areas downwind from ground zero would receive extremely hazardous dosages of radiation. It can thus be argued that decontamination procedures will probably not provide adequate protection to a population subjected to such extensive fall-out.

This does not mean that decontamination would prove to be of little value in all situations. Rather, it means that for early times (days to several weeks) following bomb detonation, a population can receive more protection from the residual radiation by staying in suitable shelters than it can by attempting decontamination. On the other hand, if suitable shelter does not exist, decontamination would be of value even during these early times.

C. The Effect of Evacuation

As seen in Figs. A and 3 of this paper, the fall-out areas extend in a long wide band downwind from ground zero. If considerable wind shear exists then these contours may be much broader, and correspondingly shorter. The effective time of onset of this fall-out depends upon the winds and the distance downwind from the detonation point. If we take as an example a point in the middle of the pattern and about 150 miles downwind (referring to Fig. 4) we find that the fall-out occurs here at about H+8 hours, and that the width of the band is about 65 miles. If persons in the center of the fall-out zone at this point remain, they would receive between 65 and 130 roentgens during the time from H+8 hours to H+2 days, even if they were in the average, best shielded positions available in a city (reference Fig. A). On the other hand, if they were able to ascertain beforehand that they were to be in such a dangerous position and could furthermore predict the shortest evacuation route which would take them out of the area to be contaminated, they could escape the fall-out hazard by moving about 35 miles. This line of reasoning presupposes that these actions could be taken between H-hour and H+8 hours, which is the time interval before appreciable amounts of fall-out reach the position. Less time for evacuation before fall-out commences would be available closer to ground zero; and, conversely, considerably more time would be available at a position a greater distance from ground zero.

Even though evacuation before fall-out begins is theoretically possible, many practical considerations weigh against it. The success of the evacuation operation would require a very accurate prediction of where the fall-out would reach the earth, and this would certainly prove to be difficult in practice. Other factors which militate against this procedure are the danger of the population being caught in the fall-out in less shielded situations than if they had not moved, and the physical difficulty of moving vast numbers of people such distances in a short time with so little advance notice. In addition, the downwind fall-out areas are so vast that if the country had been subjected to several detonations of the yield under discussion, it is conceivable that a person might find himself moving into the radiation field of a second bomb while attempting to move out of the radiation field of a first bomb.

The data presented in Table VIII (below) was calculated by considering the situation which would prevail if a population waited until the arrival of fall-out before attempting evacuation and by assuming that the fall-out pattern is known and that people can be directed along the shortest route out of the contaminated area.

Table VIII

Dosages Received if Evacuation at Time of On-set of Fall-out is Attempted; 15 MT Surface Burst

(Evacuee takes shortest route out at rate of 10 mph in automobile - shielding of the automobile reduces the radiation by a factor of 0.5)

Distance Downwind from Ground Zero	Distance Traveled (Shortest route out of contaminated area)	Time Interval for Evacuation	*Dosage Rec'd. During Evacuation	Acute Biological Effect
50 mi	32 mi	H+4 to H+7.2 hrs	~ 210r	SD/10
100 mi	42 mi	H+7 to H+11.2 "	~ 120r	probably none

* Taken to be the damage dose in assessing biological effect.

Every advantage was granted the population being evacuated in the two examples of Table VIII; hence, in an actual case, one would expect the dosages indicated to be a minimum. One must conclude, therefore, that evacuation beginning at the time fall-out reaches a position cannot be considered as an attractive defense measure.

Evacuation becomes more feasible at later times because radioactive decay reduces the dose rates of the fall-out contamination. For example, at H+2 days, evacuation achieved under the assumptions of Table VIII would result in approximately 1/20th of the dosages during evacuation indicated in Table VIII. Furthermore, evacuation at H+4 days under the same conditions would result in dosages during evacuation of approximately 1/40th of those indicated in Table VIII. An added advantage of waiting for several days in shelter before attempting evacuation is that by this time the fall-out areas would probably be fairly well known and thus the best route out of the contaminated areas could probably be chosen correctly.

D. Recommendations as to Protective Measures

From the previous discussions on decontamination and evacuation, the possibility of avoiding excessive doses of radiation by remaining in suitable shelter for several days becomes more attractive. In order to arrive at a quantitative estimate of the results of such protective measures, the information presented in Table IX below was calculated. For the purpose of this Table it was assumed that all fall-out occurred at H+6 hours. This assumption does not detract from the general import of the information disclosed by the table. However, this assumption does make the dosages given in the Table for the 1,000 square mile area problem somewhat lower than they should be, and conversely the assumption makes the dosages given in the 8,000 square mile column of the Table somewhat higher than they should be.

[redacted]

Table IX

Minimum Dosages Within Various Areas for
Shelter Situations Indicated, 15 MT Land-surface Burst

(Conditions: All persons occupy shelter from H+6 hours -- taken as time fall-out begins -- until H+4 days; they then leave shelter and receive on the average one-half of the open rural area dose rate for all time thereafter.)

Approximate Damage Dose and Acute Biological Effect	AREA 1,000 mi^2	3,000 mi^2	5,000 mi^2	8,000 mi^2
a. Fr stay in basem't of typical Eastern U.S.home (protection factor .05 to .1)	43r to 86r	20r to 40r	10r to 20r	6r to 12r
After leaving basement	180r	80r	45r	24r
Total	220r to 270r	100r to 120r	55r to 65r	30r to 36r
Acute biological effect	SD/20 to LD/1 SD/50	None	None	None
b. Fr stay in wood-frame single story home (protection factor .3 to .6)	550r to 1100r	250r to 500r	140r to 280r	75r to 150r
After leaving home	No add'l.damage	dose rec'd. due	to biological	recovery
Total	550r to 1100r	250r to 500r	140r to 280r	75r to 150r
Acute biological effect	LD/rp to LD/100	SD/25 to LD/35	SD/1 to SD/55	None to SD/1
c. From stay in commercial building, multi-story reinforced concrete (protection factor .013 to .07)	11r to 60r	5r to 27r	3r to 14r	2r to 8r
After leaving building	180r	80r	45r	24r
Total	190r to 240r	85r to 110r	50r to 60r	25r to 30r
Acute biological effect	SD/7 to SD/25	None	None	None
d. Fr stay in special shelter, below ground with at least 3 ft of earth cover (protection factor .0002)	Less than 1r	Less than 1r	Less than 1r	Less than 1r
After leaving shelter	180r	80r	45r	24r
Total	180r	80r	45r	24r
Acute biological effect	SD/5	None	None	None

[redacted]

The additional assumption that individuals outside of their shelters would receive one-half of the open rural area dose rate averaged over the course of a typical day is based upon the general results of numerous RW studies, and applies to city and urban area dwellers.

An examination of the various damage doses and their biological effects presented in Table IX demonstrates the value of an especially constructed simple underground shelter to protect against fall-out gamma radiation.

In practice the best passive defense measures would in all probability involve the occupation of shelters for time periods which would depend upon the dose rate level of the residual radiation field in the particular locality. For some areas a time of stay in the shelters of four days would be sufficient. In other more highly contaminated areas the time of stay in the shelters should be longer. For other still more highly contaminated areas it can be expected that the best passive defense would be to stay in the shelter for a week or more, and then to evacuate the area.

V. CONCLUSIONS: [redacted]

The following conclusions may be drawn regarding radiological hazards from the surface detonation of very large yield nuclear weapons:

a. The detonation of a 15 megaton yield weapon on land surface can be expected to deposit radiological fall-out over areas of about 5000 square miles or more in such intensities as to be hazardous to human life. Comparable danger areas may be involved in the case of deep water surface bursts and harbor surface bursts, with some differences in distribution likely.

b. A large percentage of the radiologically hazardous area can be expected to lie outside the range of destructive bomb effects, extending up to several hundred miles downwind; thus the radiological hazard becomes a primary anti-personnel effect.

c. The sensitive wind-dependence of the distribution of the contaminant makes accurate pre-shot prediction of the location of the hazardous area with respect to burst point virtually impossible without extensive wind data at altitudes up to maximum cloud height (about 100,000 feet).

d. The rate of decay of the contaminant is such that all but the most highly contaminated areas (a few hundred square miles) can probably be occupied by previously unexposed personnel on a calculated risk basis within a few days after the contaminating

[redacted] [redacted]

event, and even these highly contaminated areas may then be entered briefly by decontamination teams.

e. The two fundamental passive defense measures that are likely to be most effective are the seeking of optimum available shelter, and evacuation of the danger area. These two courses of action taken in succession, with the optimum time and direction of evacuation being determined and controlled by competent authority, can be expected, in effect, to reduce lethally hazardous areas by a factor of ten or more.

f. Universal use of a simple underground shelter with about three feet of earth cover could reduce areas made hazardous by fall-out radiation by a factor of a thousand or more. This means that the lethal fall-out hazard can probably be completely overcome by remaining in such a shelter for a period of a week or ten days, after which the area should be evacuated.

g. Seeking optimum shelter at once is of vital importance, since, without shelter, the dosage received in the first few hours will exceed that received over the rest of a week spent in the contaminated area; and the dosage received in a week will exceed that accumulated in the rest of a lifetime spent in the area.

APPENDIX A

Derivation of Radiation Damage Dose Formulae

In a recent study (Reference 6) it has been conjectured that damage due to radiation can be divided into a permanently retained portion which is 20% of the total received, and a remainder, which is repaired at a rate represented by an exponential decay law. Thus, if D_o is an acute dose received at time $t = 0$, the "damage dose" at time t is given by

$$D(t) = 0.2\, D_o + 0.8\, D_o e^{-\beta t}, \qquad (1)$$

where β is the decay constant. Experimental evidence indicates that the decay constant has a value of about 0.29.

In this report it has been assumed, as was done in Reference 1, that the dose continuously received from a decaying radioactive field can be treated in the same manner. If the dose rate is given by

$$R(t) = kt^{-1.2}, \qquad (2)$$

where k is the rate at time $t = 1$, then the damage dose at any time T, assuming the individual entered the field at time T_o, is

$$D(t) = \int_{T_o}^{T} \left[0.2 + 0.8e^{-\beta(T-t)}\right] kt^{-1.2} dt \qquad (3)$$

$$= (T_o^{-0.2} - T^{-0.2}) + 0.8ke^{-\beta T} \int_{T_o}^{T} e^{\beta t} t^{-1.2} dt.$$

The integrand in the above expression can be plotted and the definite integral

$$A\,(T) = \int_{0.25}^{T} e^{\beta t} t^{-1.2} dt \qquad (4)$$

[redacted]

[redacted]

evaluated for various values of T by planimeter. Using equation (4), D(T) is given by

$$D(T) = k(T_o^{-0.2} - T^{-0.2}) + 0.8ke^{-\beta T}\left[A(T) - A(T_o)\right]. \qquad (5)$$

Equation (5) was used in this paper to calculate the maximum dose for simple cases by calculating D(T) for various values of T until a relative maximum was obtained.

If an individual is in a radiation shelter from time T_o to time T_1 and then emerges, equation (3) must be altered to take into account the fact that from time T_o to T_1 the constant k has one value, k_1, and from time T_1 to T a different value, k_2. In this case then,

$$D(T) = \int_{T_o}^{T_1}\left[0.2 + 0.8e^{-\beta(T-t)}\right]k_1 t^{-1.2}dt$$

$$+ \int_{T_1}^{T}\left[0.2 + 0.8e^{-\beta(T-t)}\right]k_2 t^{-1.2}dt$$

$$(T_o < T_1 > T). \qquad (6)$$

This form can be simplified to give

$$D(T) = k_1\,(T_o^{-0.2} - T_1^{0.2}) + 0.8k_1e^{-\beta T}\left[A(T_1) - A(T_o)\right]$$

$$+ k_2(T_1^{-0.2} - T^{-0.2}) + 0.8k_1e^{-\beta T}\left[A(T) - A(T_1)\right] \qquad (7)$$

Equation (7) was used to find a second relative maximum damage dose (if any) which occurs after an individual leaves shelter. This can be compared with the first relative maximum occurring before he leaves the shelter. The largest of these is, of course, the maximum damage dose during the time interval considered.

[redacted] [redacted]

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(1) WSEG Report No. 9: "An Evaluation of U.S. Capabilities in 1956 and 1960 for Employment of Radiological Warfare Weapons Systems in Air and Ground Operations", October 1953. TOP SECRET, Restricted Data.

(2) Headquarters, JTF-7 letter, subject: "Radiological Surveys of Several Marshall Island Atolls", dated 18 March 1954, with enclosures. SECRET, Restricted Data.

(3) AFSWP 351-B: "Super Effects Handbook", Second Revision, December 1953. SECRET, Restricted Data.

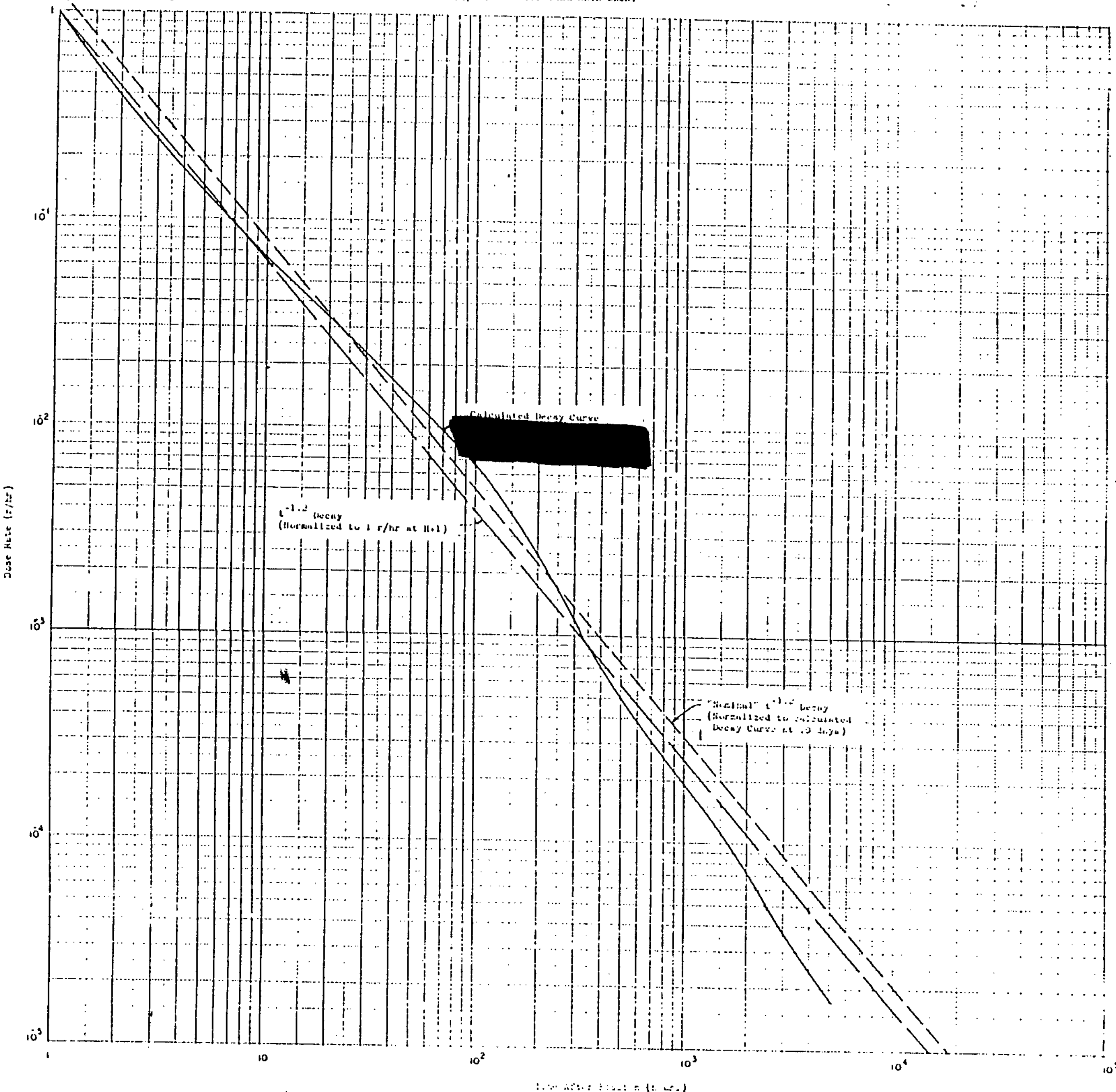
(4) USNRDL Draft Paper 006705: "Scaling of Contamination Patterns, Surface and Underground Detonations", Ksanda, Minvielle, and Moskin, 1953. SECRET, Restricted Data.

(5) USNRDL-387: "Contribution of Different Chemical Elements to the Rate of Gamma Radiation at Various Times After an Underwater Atomic Burst", W. J. Heiman, November 1952. SECRET, Restricted Data.

(6) E. H. Smith & Company: Informal Study for the Chief, AFSWP; 1953. Unclassified.

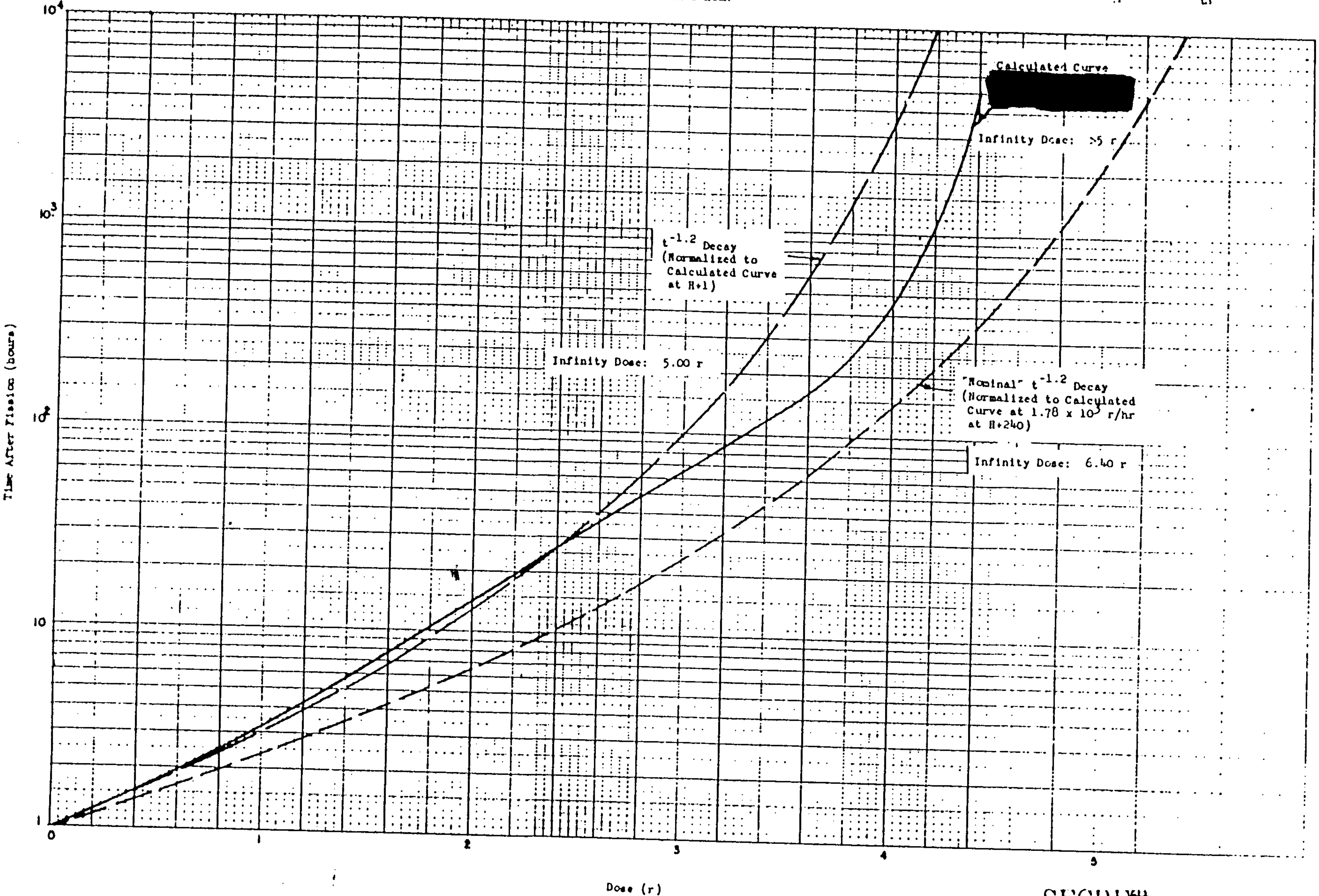
[redacted] [redacted]

FIG. 1 GAMMA DOSE RATE DECAY



[redacted]

Fig. 2 TOTAL GAMMA DOSE FROM 1-HOUR



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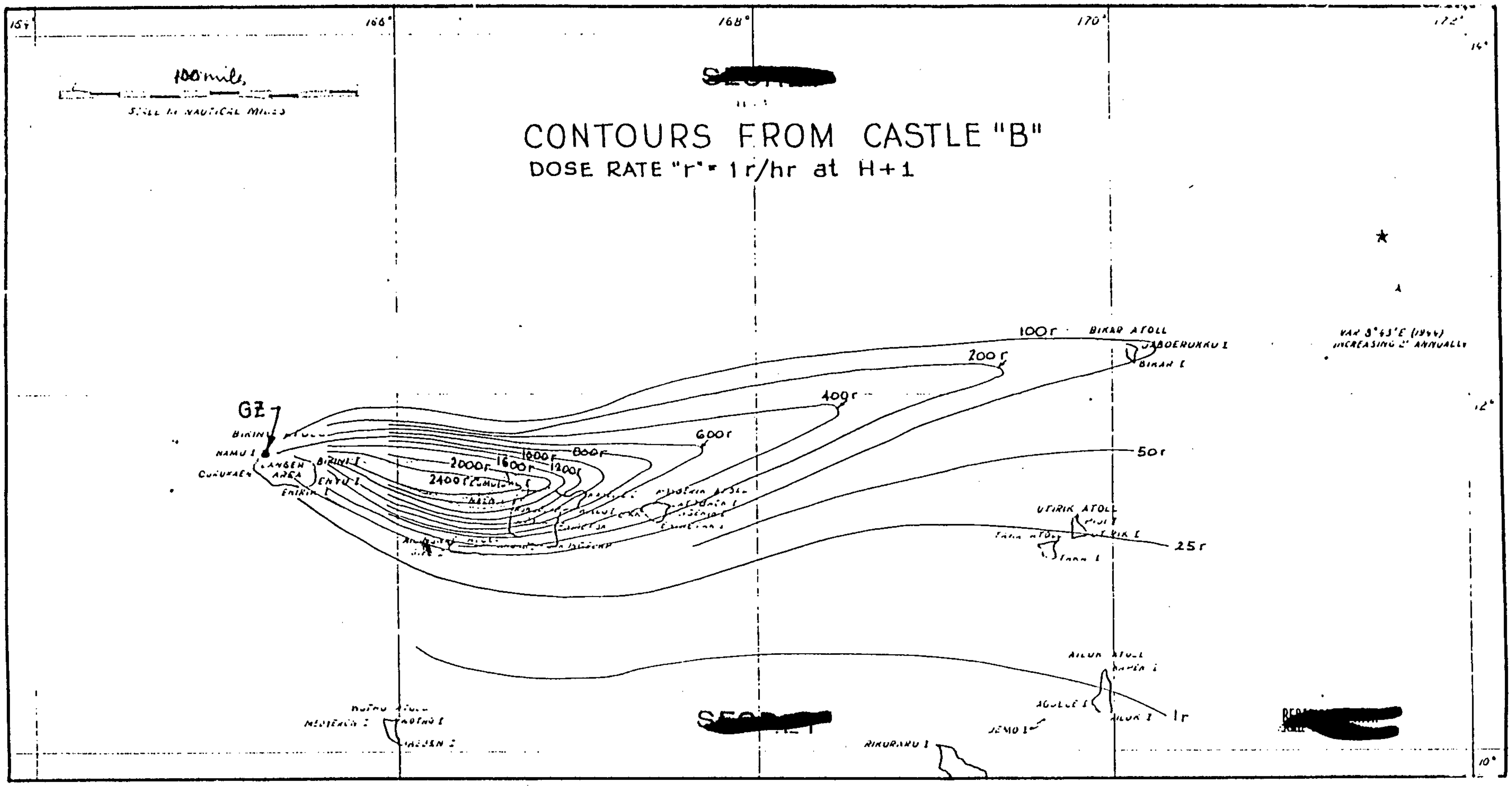
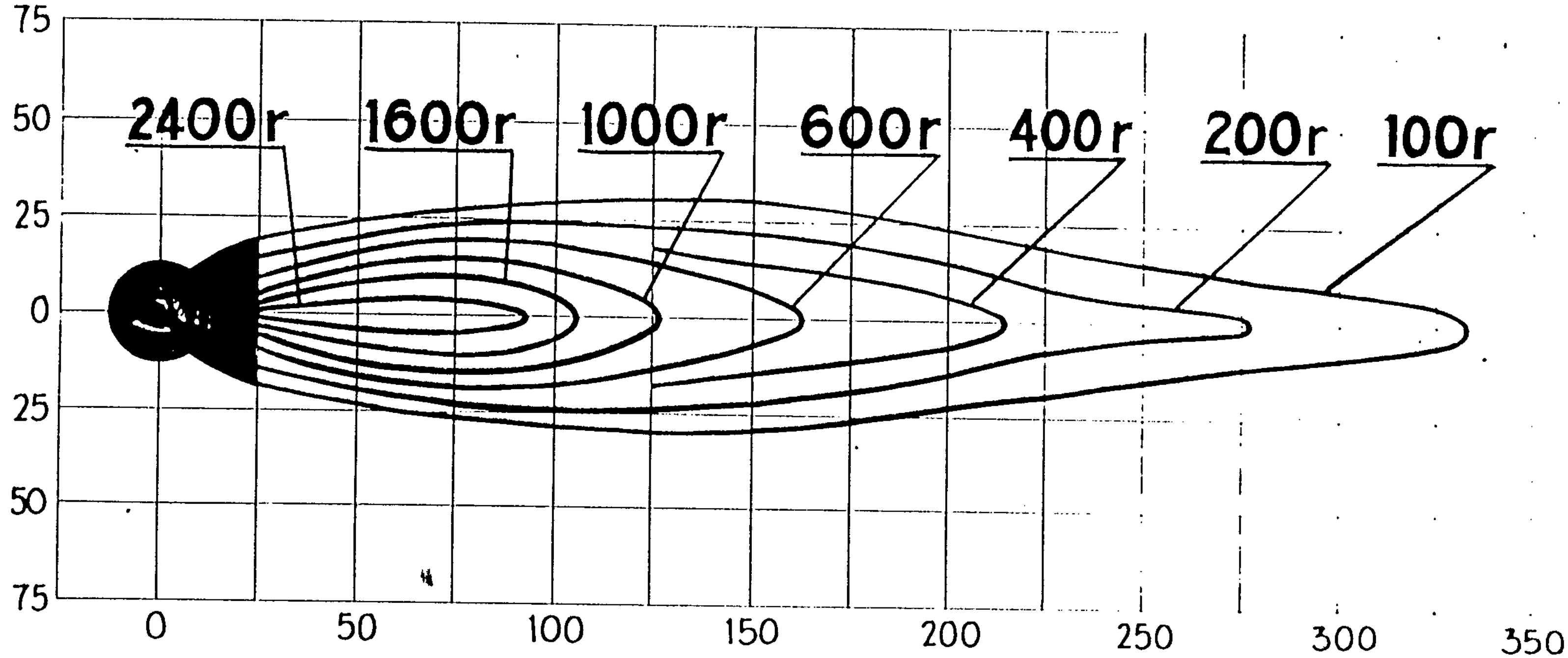


S[redacted]
CONTOURS FROM CASTLE "B"
DOSE RATE "r" = 1 r/hr at H+1
100 miles
SCALE IN NAUTICAL MILES
166°
168°
170°
172°
14°
12°
10°
GZ
BIKINI ATOLL
NAMU I
LANGEN AREA
BIKINI I
ENYU I
ENIKIN I
100r
200r
400r
600r
800r
1200r
1600r
2000r
2400r
50r
25r
1r
BIKAR ATOLL
JABOERUKRU I
BIKAR I
UTIRIK ATOLL
AILUK ATOLL
AILUK I
JEMO I
BIKURAKU I
VAR 8°45'E (1944)
INCREASING 2' ANNUALLY
S[redacted]
[redacted]

FIG. 4

IDEALIZED FALL OUT CONTOURS



SCALES IN STATUTE MILES "r" = 1 r/hr. at H+1

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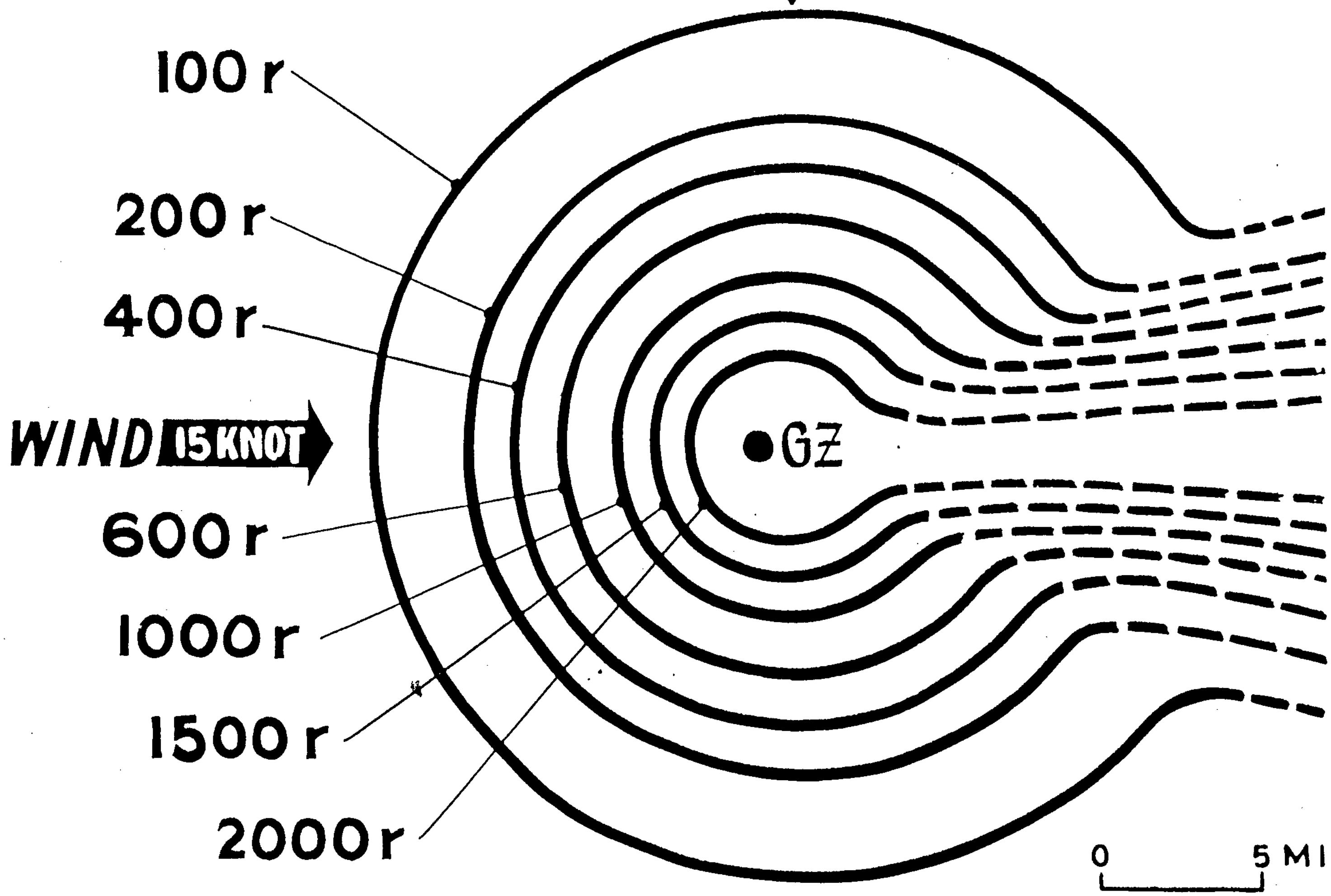
FIG. 5 **GZ CONTOURS 15 MT (LAND)**

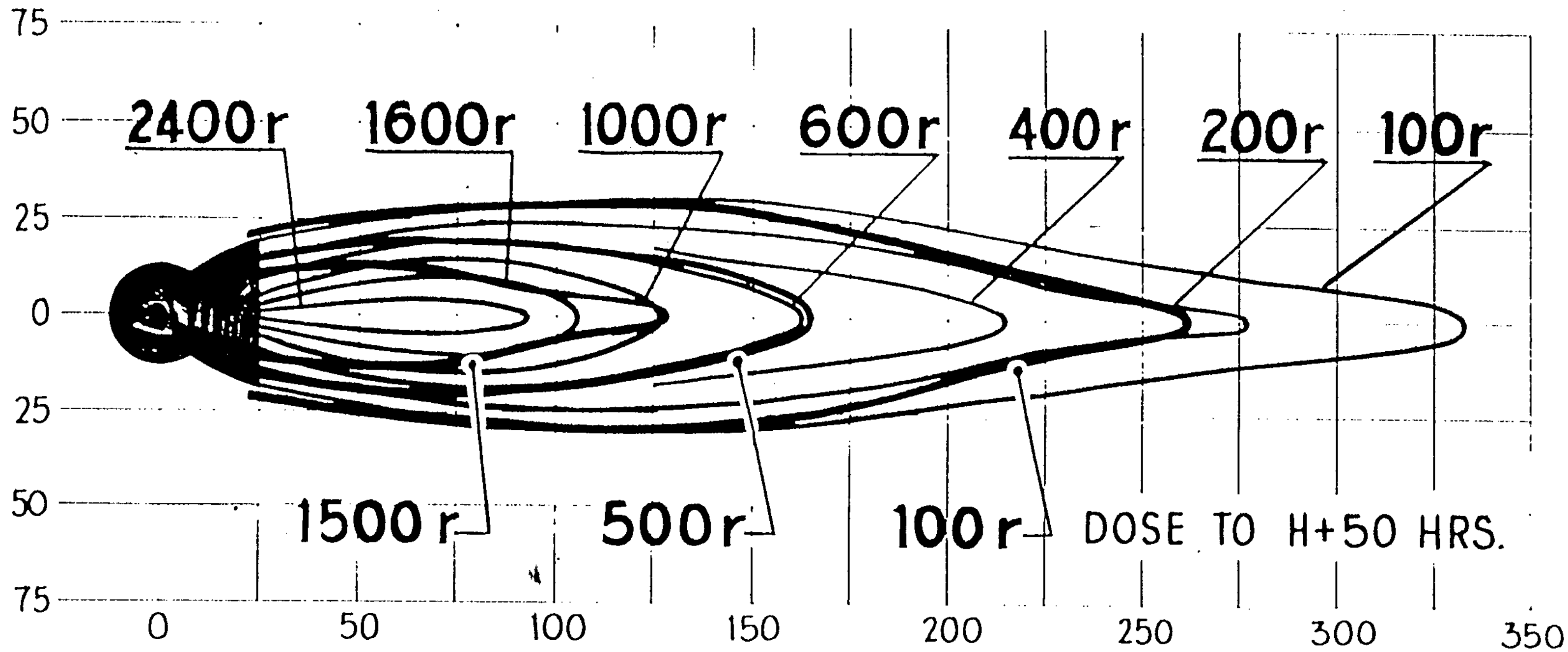


• "r" - 1 r/hr at H+1

~~SECRET~~ ~~RESTRICTED~~

FIG. 6

IDEALIZED FALL OUT CONTOURS



SCALES IN STATUTE MILES "r" = 1 r/hr. at H+1

CONFIDENTIAL

IDEALIZED LOCAL CONTOURS
• FOR RESIDUAL RADIATION

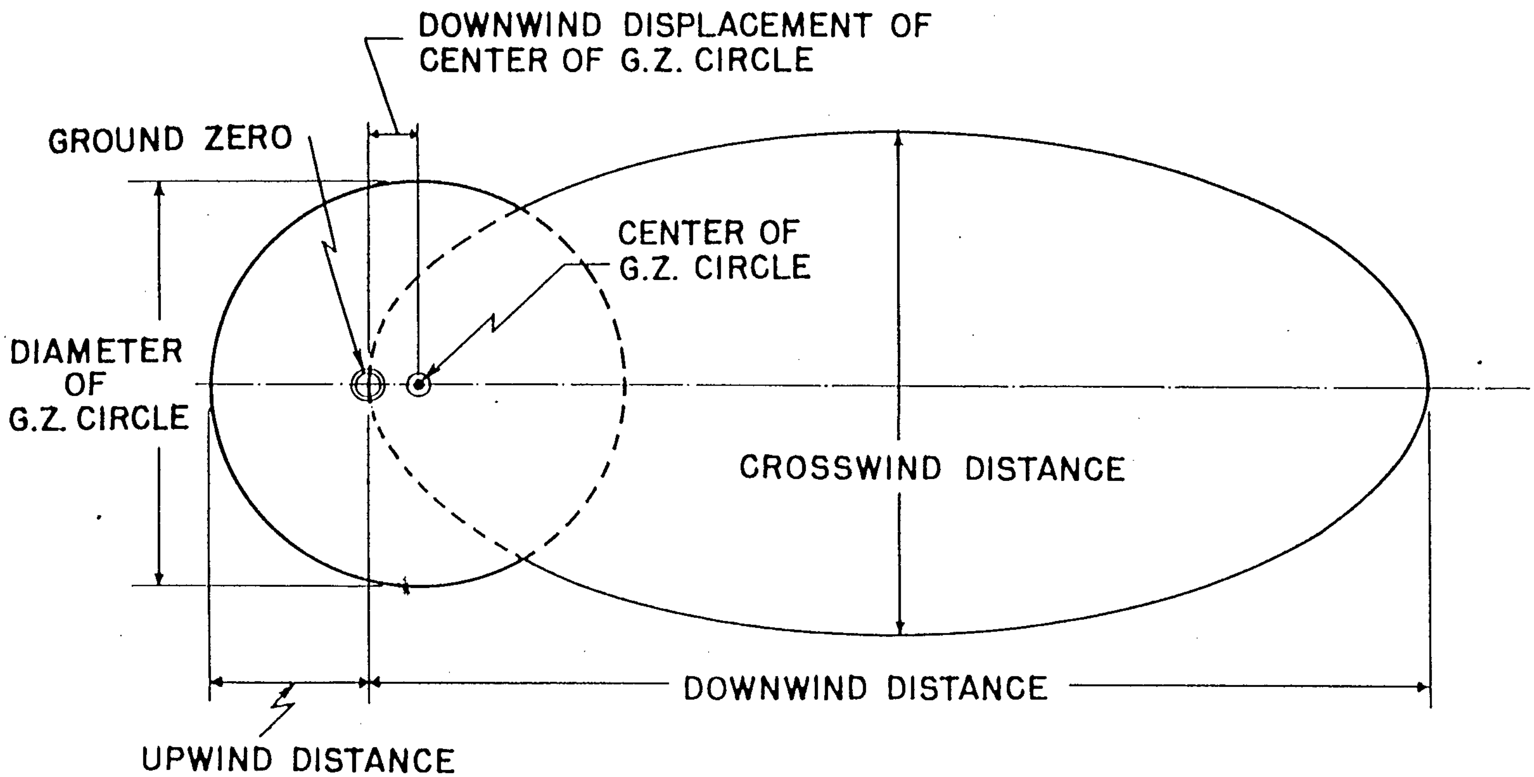
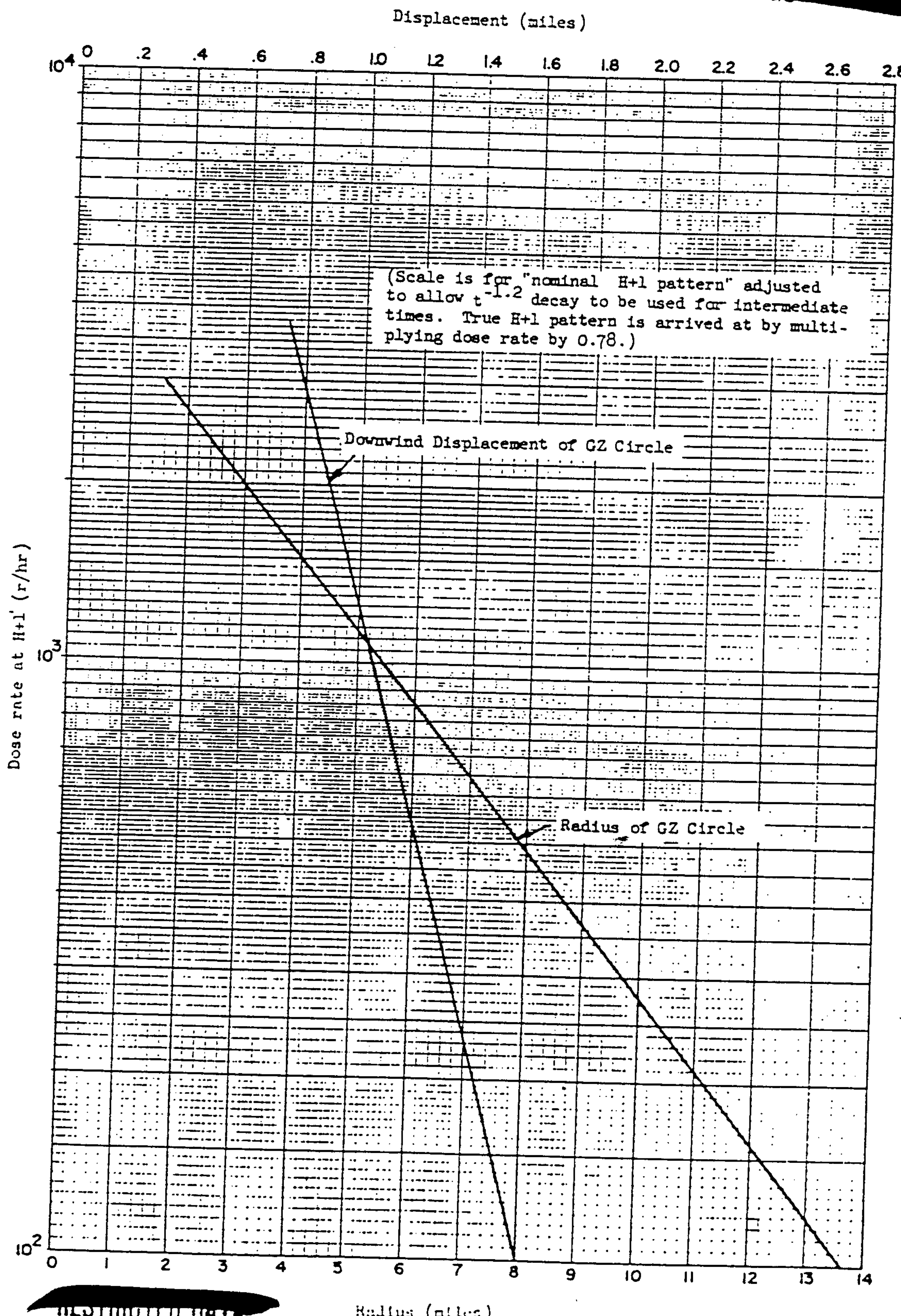


FIG 7

CONFIDENTIAL

Fig. 8 RADIUS AND DISPLACEMENT OF GZ CIRCLE

15 MT at H+1 reference time; 15 knot effective wind. [redacted]

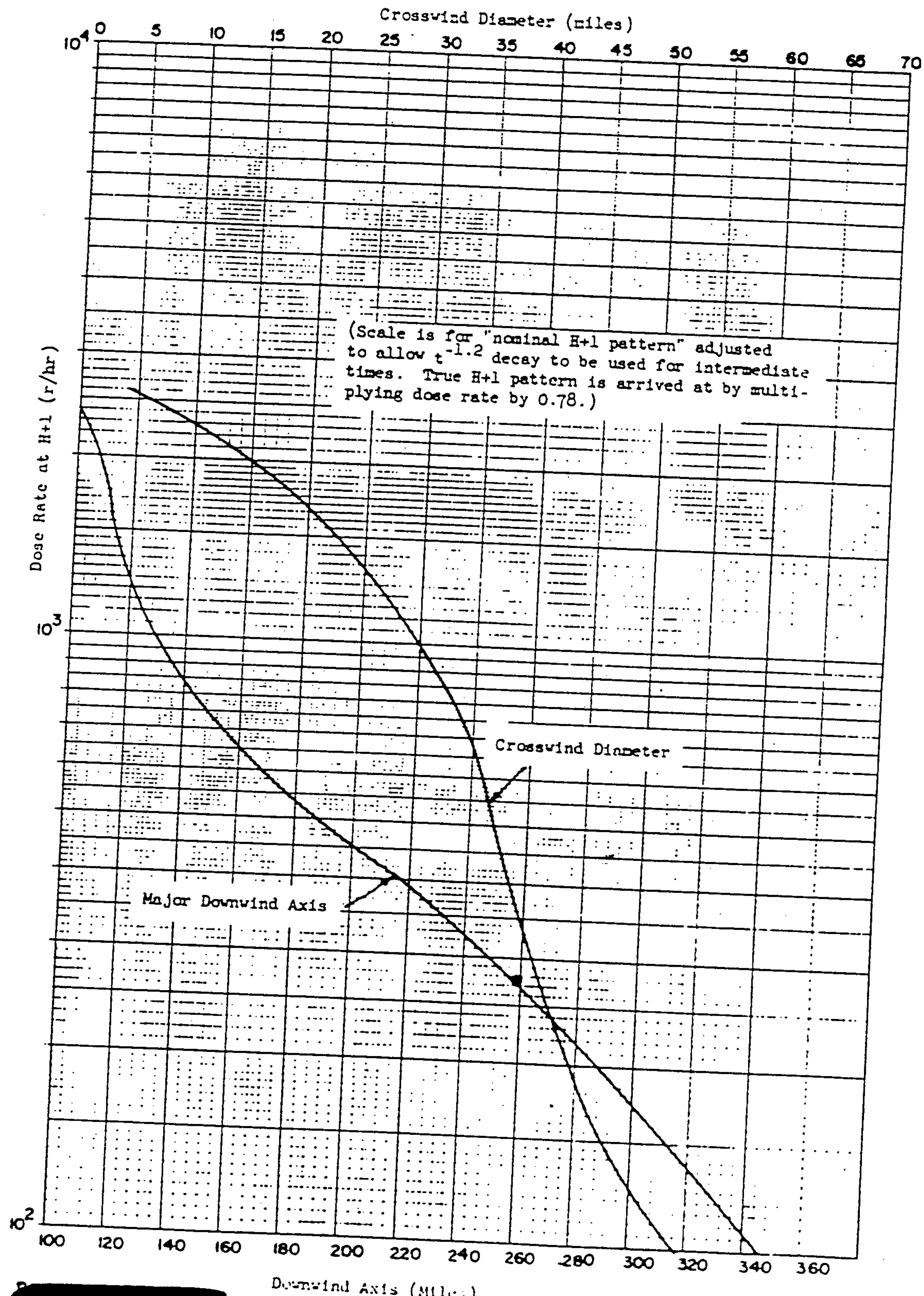


[redacted]

[redacted]

Fig. 9 DOWNWIND AND CROSSWIND AXES OF DOWNWIND PATTERN

15 MT at H+1 reference time; 15 knot effective wind. [redacted]

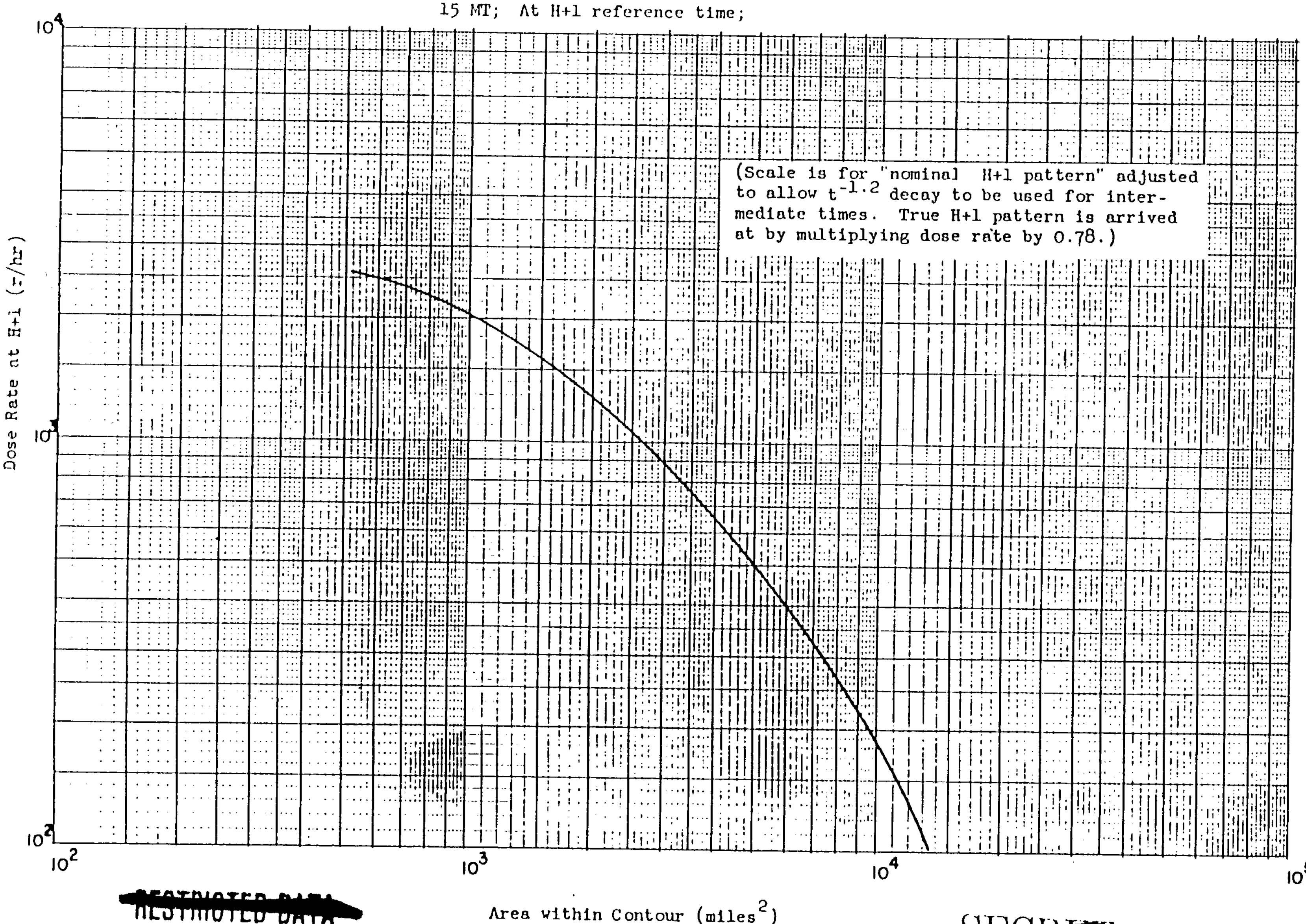


[redacted]

[redacted]

[redacted]

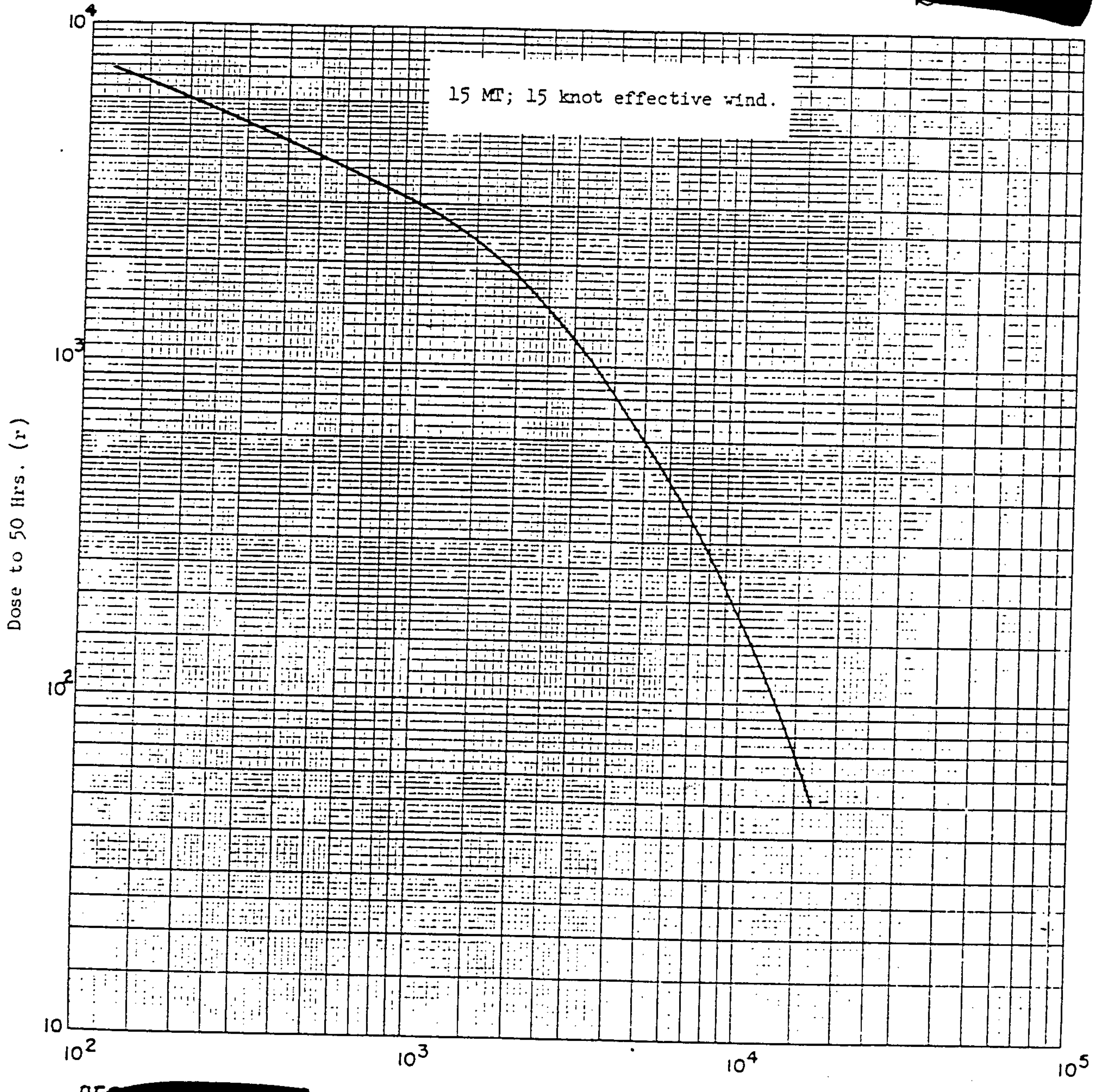
Fig. 10 AREA OF DOSE RATE CONTOURS
15 MT; At H+1 reference time;



[redacted]

[redacted]

Fig. 11 AREAS OF FALL-OUT TO 50-HOUR TOTAL DOSE [redacted]



[redacted]

Area Receiving Dose (miles^2)

[redacted]

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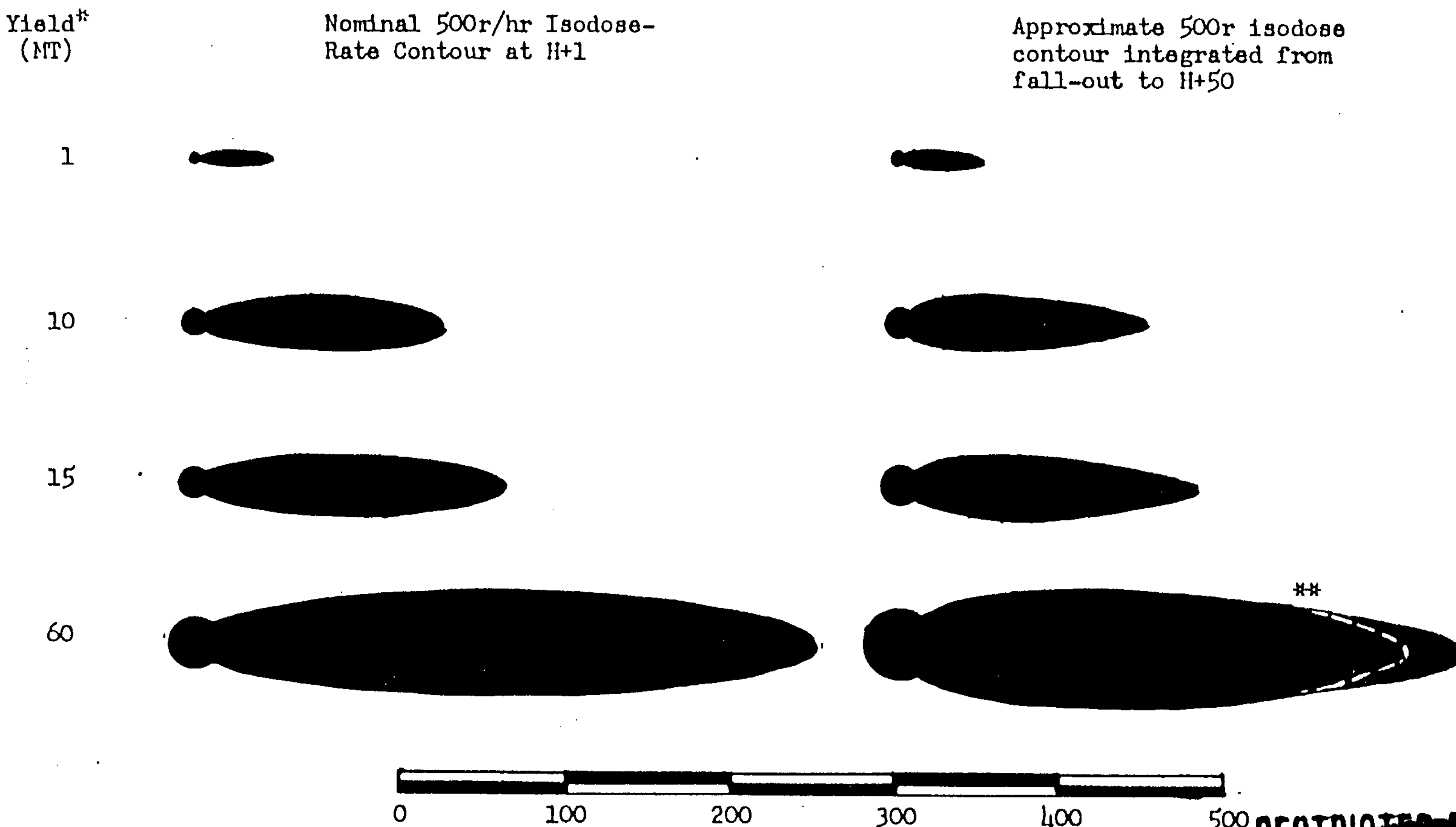
Fig. 12 SCALING OF REPRESENTATIVE IDEALIZED FALL-OUT CONTOURS WITH YIELD



**Accurate Contour for 60 MT (Chapter III, G)

~~RESTRICTED DATA~~ [redacted]

~~SECRET~~ [redacted]

Defense Special Weapons Agency
6801 Telegraph Road
Alexandria, Virginia 22310-3398

TRC

28 July 1998

MEMORANDUM TO DEFENSE TECHNICAL INFORMATION CENTER
ATTENTION: OCQ/Mr. William Bush

SUBJECT: Submittal of AFSWP-507-SAN

The Defense Special Weapons Agency Technical Resource Center is submitting the enclosed sanitized document for inclusion into the DTIC collection:

AFSWP-507-SAN
Radioactive Fall-Out Hazards From Surface Bursts of
Very High Yield Nuclear Weapons, Sanitized Version.

Distribution statement **"A"** applies to this sanitized version only.

Please notify this office of the DTIC accession number as soon as possible, since there are waiting requesters.

Ardith Jarrett
ARDITH JARRETT
Chief, Technical Resource Center

Attachment:
A/S